Electronic Engineering

INCORPORATING ELECTRONICS, TELEVISION AND SHORT WAVE WORLD

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Dust Cored Coils

Physics of the Hard Vacuum Valve

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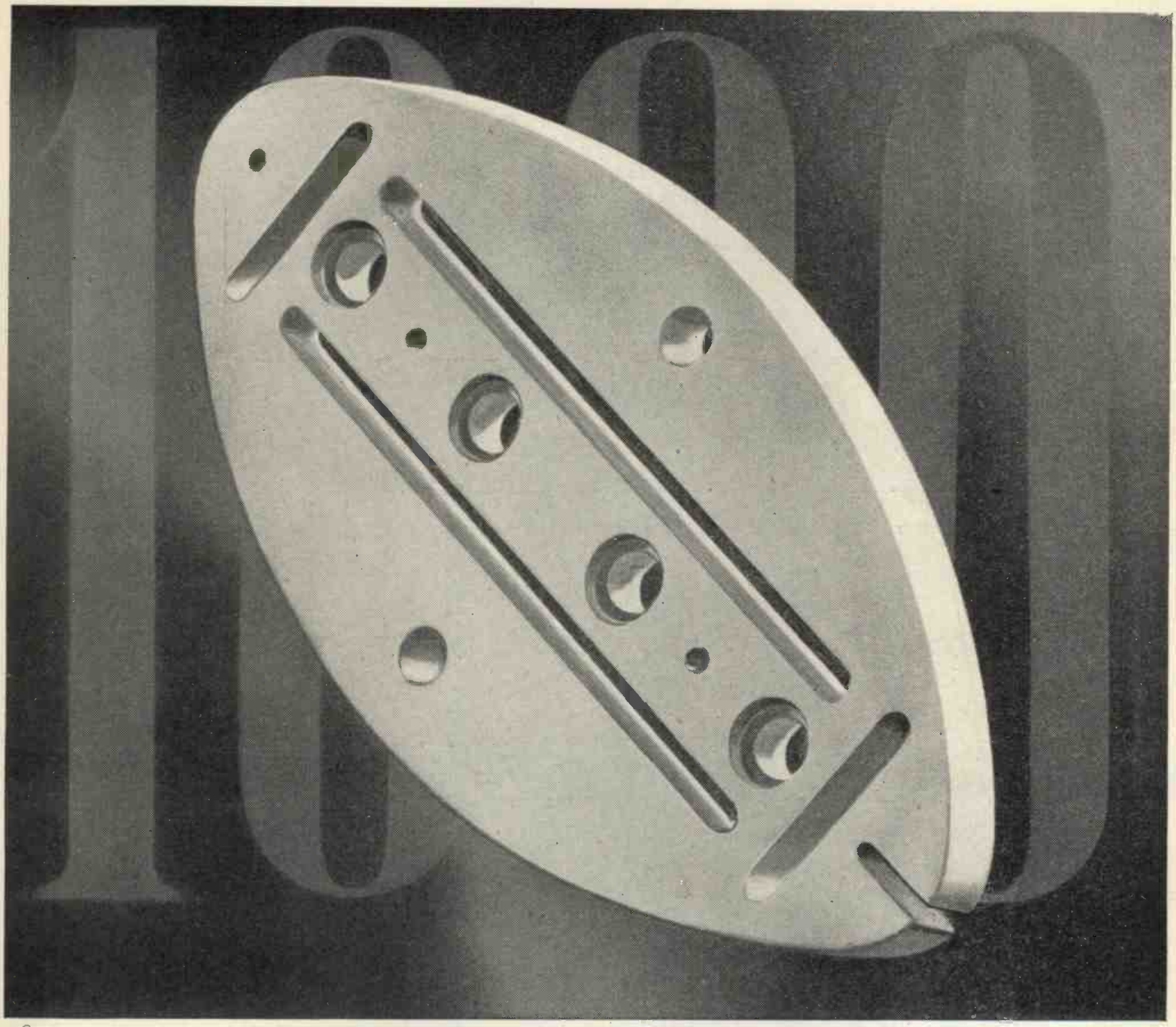
Aerial Characteristics — Data Sheet

2/- AUG., 1943



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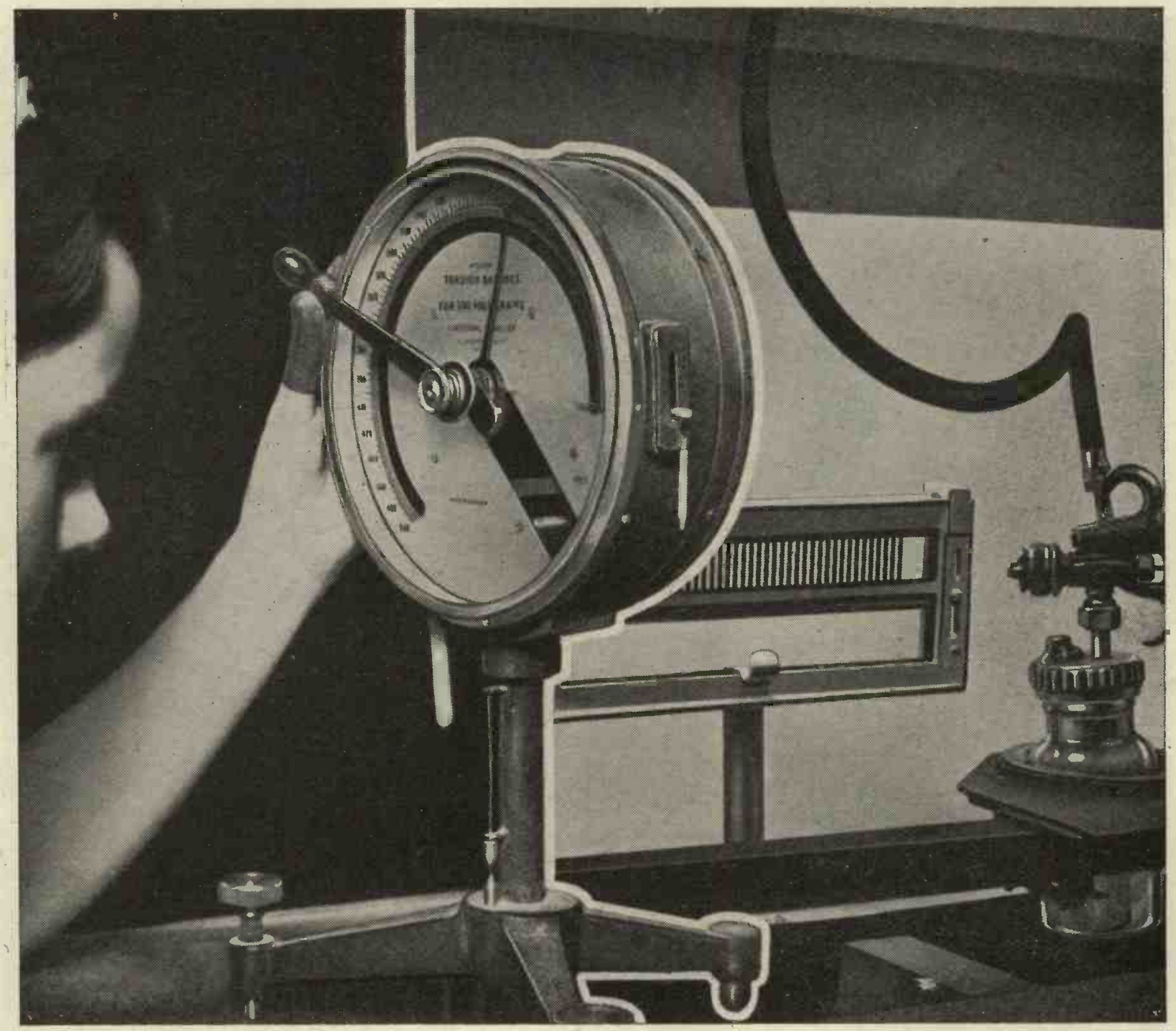

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Electronic Engineering

AUGUST, 1943

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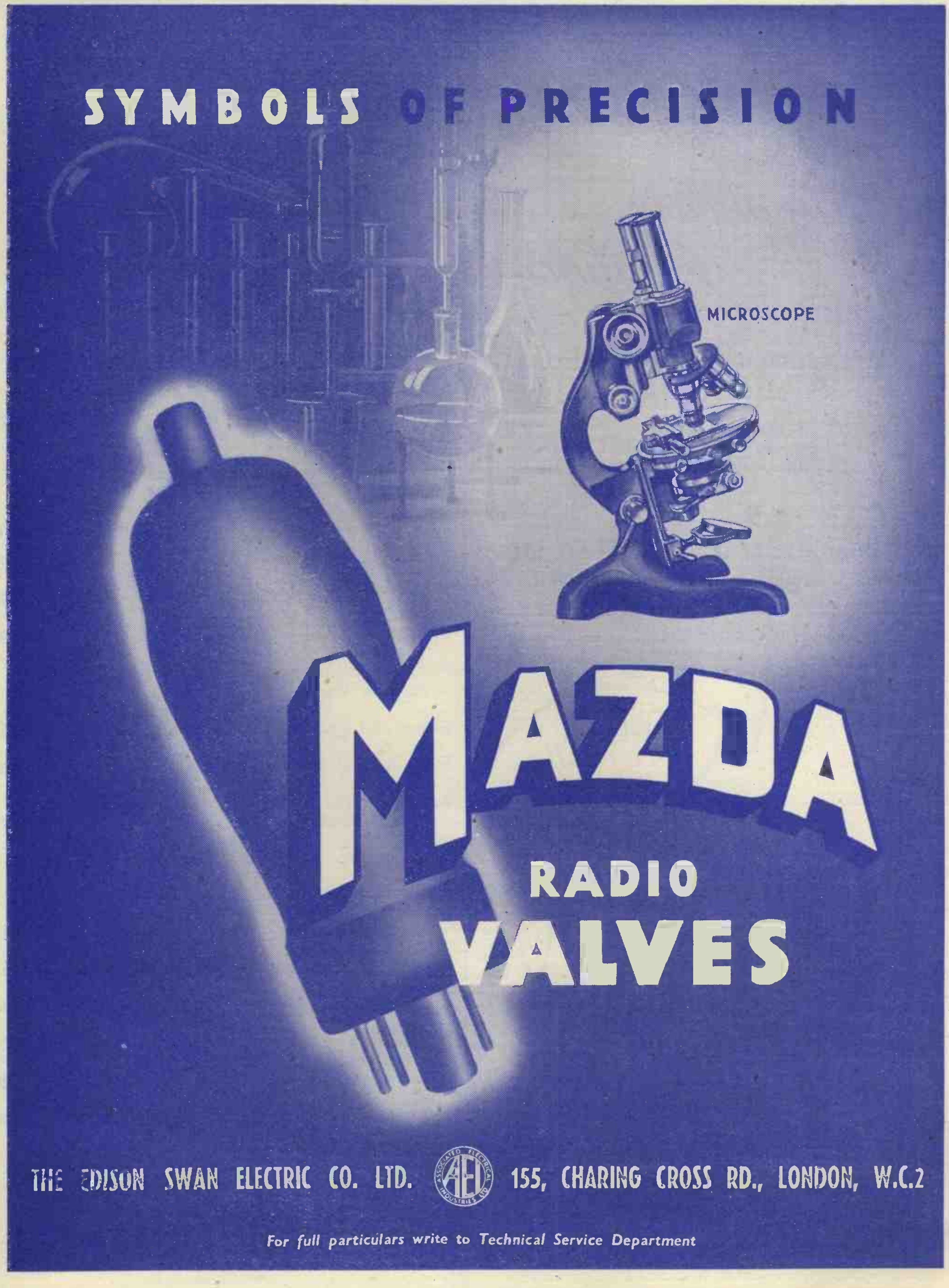
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Words

OUR contemporary, *Radio News*, which is published in Chicago, has announced its intention for the future of referring to the science of "pure and applied radio" as RADIONICS.

In a long Editorial note* justifying their decision, the word is defined literally as "travelling radiation" with additional emphasis on the "ion" part, denoting a charged particle.

". . . . The word thus takes on a greater significance. We have in it radiation, charged particles, the coverage for future developments in radio technique (an act or process using some new ultimate particle) . . '

The word ELECTRONICS is condemned on three counts:

(1) Its literal meaning is "wandering amber."

(2) The scientific connotation can stand for only a particular charged particle, justified primarily by being a fundamental charge and historical value (*sic.*).

(3) There is no implication of radio technique as thought of by the public, and this causes misunderstanding . . . .

Finally, we are surprised to learn that ELECTRONICS is a British term, whereas RADIONICS is pure American. It is the general impression over here that ELECTRONICS was coined by the McGraw Hill Co., so we are smarter than we thought.

Anyhow, whoever coined it, it is a most useful word, and we think that *Radio News* should make out a better case for abandoning it. On the first count, it is not profitable to attack the etymology of any English word—you never know where you may land. Talking of etymology, why not start a campaign for altering electrocution into electrocussion, which is more accurate?

The justifications in the second count seem quite sound. The electron is both a fundamental charge and an historic term, and the science should therefore be associated with this basic word.

On the third count, the muddle-headed attitude of certain members of the public to science is the despair of scientists, and it is doubtful whether the use of one term instead of another will help to clear their brains. It is up to scientists to help the public appreciate the true meaning of electronic developments, and they are not helped in this by the ballyhoo which has appeared recently in certain publications.

In judging the merits of the two words, we would sooner apply the tests suggested by A. P. Herbert:† Ask the new word the following questions: Are you intelligible? Are you pleasing? Are you legitimate? Are you needed?

And judged by these standards, we respectfully suggest that RADIONICS is an also ran.

Mr. Hugo Gernsback, of *Radio-Craft*, has also taken up the cudgels on behalf of ELECTRONICS. There is only space to quote the beginning and ending of his remarks:‡

"We have noticed an unfortunate attempt from several quarters to befuddle the public with the term RADIONICS. Why this red herring should be dragged across the well-established ELECTRONICS trail at this late date seems a profound mystery . . . . "

" . . . . In 1924 I coined the humorous word RADIOTICS for a radio joke column. Maybe that is the less befuddling term."

Good for you, Mr. Gernsback! In the meantime, we should worry.

* *Radio News*, May 1943, p. 4.

† *What a Word!* (Methuen) p. 237.
‡ *Radio-Craft*, May 1943, p. 463.

Index to Vol. XV.

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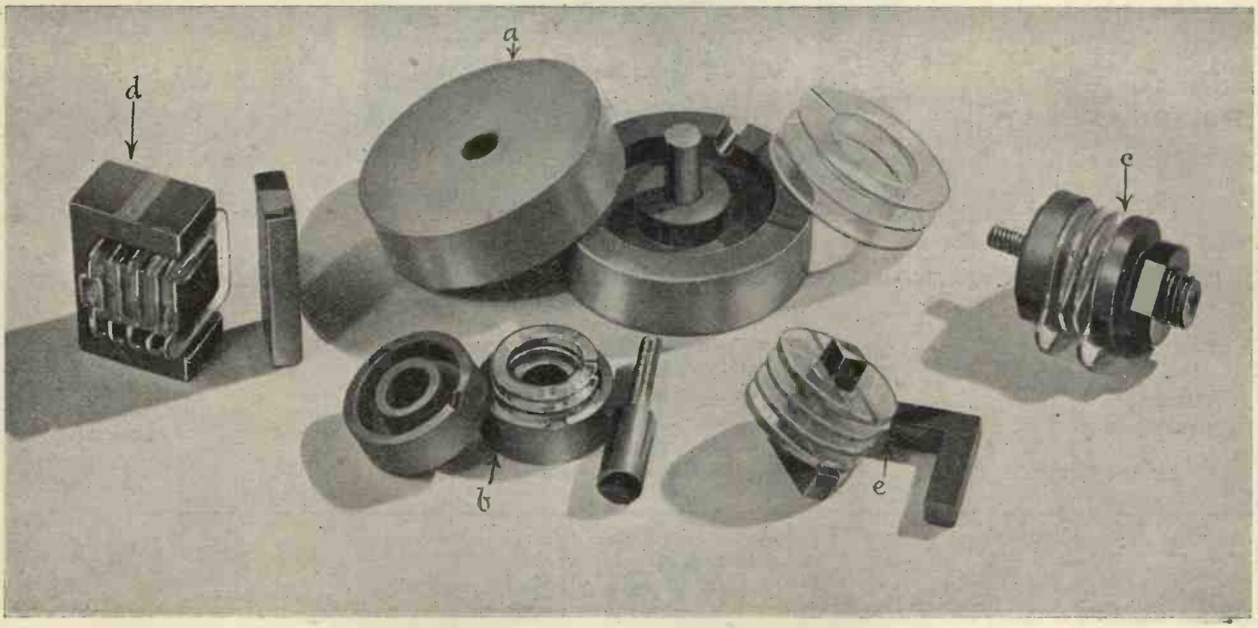


Dust Cored Coils

Part I. The Development of Dust Core Materials

A review of the design and applications of dust-cored inductance coils, showing how a detailed analysis of the losses enables the performance of a given coil to be calculated from a limited number of test measurements

By V. G. WELSBY, B.Sc. (Eng.)*

IT is well-known that if an alternating current is passed through a coil surrounding a solid ferromagnetic core, circulating currents, or eddy currents will be induced in the core. These currents, flowing against the electrical resistance of the core material, will dissipate energy in the form of heat. The amount of energy lost in this way and the resulting temperature rise may be quite insignificant, but what is usually far more important is the damping effect produced in any resonant circuit of which the coil may form a part. Other factors being equal, the eddy current effect increases approximately as the square of the frequency of the applied voltage, with the result that the problem of minimising these losses rapidly becomes more acute as the frequency is raised. At low frequencies, eddy current losses can be kept sufficiently small by dividing the core into a series of laminations, insulated from each other so that the effective resistance presented to the eddy currents is increased. As the frequency is raised, the tendency for the losses to rise can at first be compensated by dividing the core into thinner and thinner laminations, but this process obviously cannot be continued indefinitely. Generally speaking it is not practicable to use laminations with a thickness less than about 0.002 inch, owing to difficulties in manufacture and assembly. From the point of view of economics, too, the cost would rapidly become prohibitive as the thickness of the lamination was reduced owing to the increased number of laminations and the rising labour costs. As an alternative, a further subdivision of the core can be obtained by imagining the laminations as being split into thin strips separated by layers of insulation; in other words by building the core up in the form of a bundle of insulated wires of magnetic material. Such cores have been used, (*e.g.,* induction coils used in telephone instruments, etc.) but their application is limited by cost and the difficulty of forming cores with closed magnetic paths.

The idea of building cores of discrete particles of magnetic material, each surrounded by insulation, is by no means new, but some years elapsed before any satisfactory results were obtained. The first commercial dust-core material was produced in America by the Western Electric Co. about 1915.[1] The magnetic material used was iron which was reduced to powder by casting it (or depositing it electrolytically) in a brittle form and pulverising it in a suitable mill; the powdered iron was then coated with shellac and pressed into ring-shaped cores under a pressure of about 100 tons per square inch. Materials of this type were extensively used at speech frequencies in loading coils for telephone circuits. The next step forward was about 1928, when the Bell Laboratories in America perfected a method of producing cores composed of compressed powdered "permalloy"[2] (a high-permeability nickel-iron alloy). The permeability of this material showed an increase of about 50 per cent. over that of the iron-dust cores, resulting in a corresponding reduction in the dimensions of coils having a given performance.

The early dust-core materials were still not sufficiently finely-divided to enable them to be used at radio frequencies, and an interesting material,

* Post Office Research Station.

The illustration at the head of this page shows a typical selection of dust-cored coils in use at the present time. (a) 'pot' core, (b) 'pot' core with screw adjustment, (c) 'Cotton-reel' core, (d) 'E & I' core, (e) 'L' core. (Approximately ⅞ full size).

known as "Ferrocart,"[3] was developed at about the same time in Germany in an attempt to overcome this difficulty. It was formed by sprinkling long thin particles of iron on a sheet of paper, orientating the particles by means of a magnetic field so that they were all lying parallel, and then securing them in position with a suitable adhesive. A number of such sheets were then formed under pressure into a solid mass which could be worked into any required shape. The material was, of course, used in such a way that the axis of the particles lay along the path of the magnetic flux in the completed coil. The fact that the particles were widely separated and each presented a small cross-sectional area at right-angles to the flux enabled the eddy-current losses to be reduced sufficiently to make Ferrocart suitable for use at frequencies hitherto unattainable with any form of iron core. Ferrocart has now been largely superceded by improvements in the technique of producing finely-divided iron dust. Nowadays, iron dust is often produced chemically by the "carbonyl" process.[4] The first stage is the formation of a compound of iron and carbon monoxide, known as iron pentacarbonyl, which exists at room temperatures as a liquid. It is easily vaporised, and on further heating, decomposes once again into carbon monoxide and metallic iron. Under suitable conditions, the iron can be condensed in the form of tiny spherical particles ranging in diameter from 0.5 to 5.0 microns (1 micron = 0.001 mm.). Dust obtained in this way is particularly suitable because not only is it finely divided, but also the spherical form of the particles reduces the tendency of the latter to burst through the insulating layers when the core is subjected to the forming pressure. "Carbonyl" cores are extensively used for radio tuning coils and for apparatus (such as wave filters) used in carrier telephony.

Specific Permeability

The specific permeability μ of a dust core material is defined as the average permeability of a sample which is sufficiently large to enable it to be regarded as homogeneous. If such a sample is placed in a magnetic field, the flux will pass successively through particles of high permeability and insulating layers with a permeability which may be taken as unity. It is easy to see, therefore, that the specific permeability is going to depend rather on the number and thickness of the insulating layers rather than on the permeability μ_0 of the particles. Fig. 1 gives some idea of the way in which μ depends on μ_0 and on the percentage of the total volume of the material which is occupied by insulation.[5] It will be noticed that as the percentage of insulation is increased, μ tends to become independent of μ_0, so that from the point of view of permeability there would be no advantage in using high-permeability alloys in place of iron in such cases.

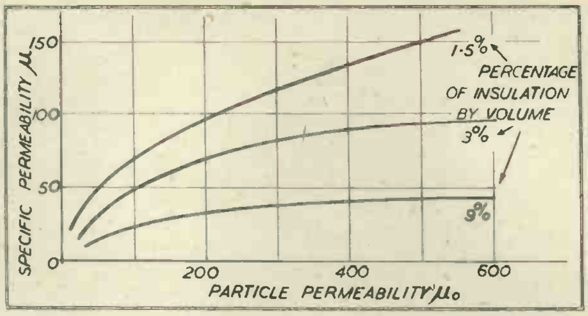


Fig. 1.1. Relationship between specific permeability and particle permeability for different percentages of insulation.

Effective Permeability

The effective permeability μ_e is defined as the ratio between the inductance of a coil in air and the inductance of the same coil when the core under consideration is introduced. If the coil could be completely embedded in a large mass of the core material, μ_e would obviously be equal to μ_0. In practice, however, this maximum cannot be attained,* since, as a result of the relatively low specific permeability it is impossible to ensure that all the flux linking with the coil will flow in the core without any leakage. It does not follow that the design of core which gives the highest value of μ_e for a given material is necessarily the best. This point will be dealt with in more detail in Part 2, but the broad principle will be stated here that the optimum value of μ_e tends to fall as the frequency is raised. Thus the best design for a certain frequency might be a toroidal core in which $\mu_e \doteq \mu = 12$; while at some higher frequency, better results might be obtained with the same material by changing over to a different shape of core for which μ_e might be as low as 3. It can be shown, in fact that a limiting frequency exists for a given material and coil size, above which no advantage is gained by introducing the dust core. This limit is reached when the increased losses due to the introduction of the core begin to outweigh any advantages gained by the rise in inductance, even for very small amounts of core material.

Other Sources of Power Loss

Up to now we have considered the problem of core materials from the point of view of eddy-current losses only, but there are two other sources of loss which have influenced the development of dust cores and which will be referred to briefly here. It is proposed to discuss them more fully in Part 2. Firstly, there is the hysteresis loss which takes place when any ferromagnetic material is placed in an alternating magnetic field. Although hysteresis may contribute only a small proportion of the total losses, nevertheless it may be very important because it causes distortion of the waveform of currents flowing in the coil. This means that if a sinusoidal alternating voltage is applied to the coil, hysteresis will cause distortion of the current wave, resulting in the production of components at harmonic frequencies which did not exist in the applied signal. This production of unwanted frequencies may cause serious difficulties in apparatus such as a multichannel carrier telephone system. The second source of loss is, for the lack of a better term, usually referred to as the "residual loss," although in some literature on the subject, the German term "nachwirkung" or "after-effect" will be found. The exact significance of this loss has led to some controversy, but it seems to be generally accepted that it is due to internal stresses in the material, produced by the magnetostriction effect. Residual loss can be minimised by careful annealing of the dust particles. The existence of these two sources of loss has led to the development of several alloys having certain special properties, although particularly at higher frequencies, the best results have so far been obtained with carbonyl iron dust.

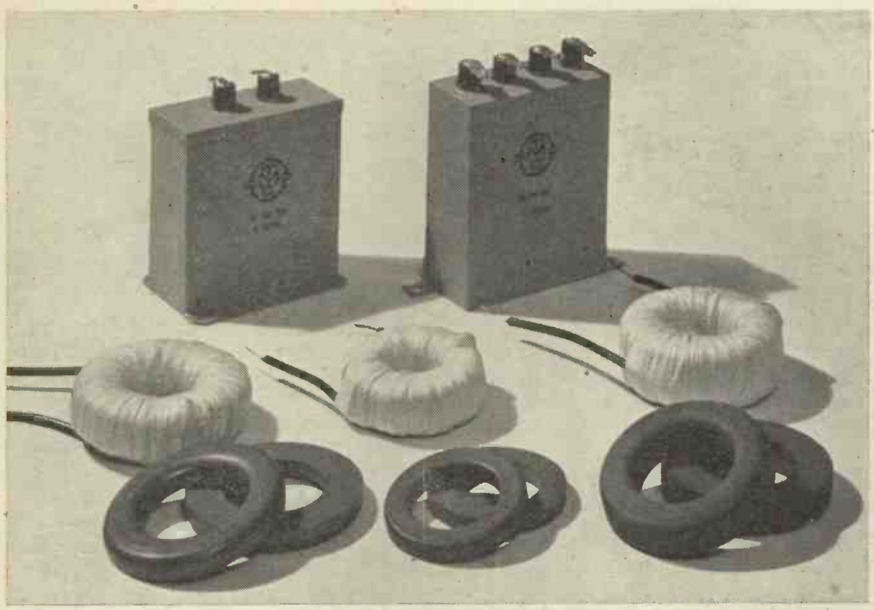
Types of Core

Dust cores can be pressed in a wide variety of forms, but these can be classified roughly as follows:

1. Solenoid

The simplest type of core consists of a "plunger," usually of circular cross-section, which is inserted through the centre of the coil bobbin. For reference purposes, this will be called the solenoid type. Since the magnetic circuit is not closed, the effective permeability will be low, so

* It can be closely approached in carefully designed toroidal (ring-shaped) cores.



Toroidal filter cans, coils, and dust cores.

(By courtesy of the Telephone Mfg. Co.)

that solenoid cores are most suitable for use at high frequencies. The plunger is often fitted with a screwed brass rod to enable fine adjustment of the inductance of the coil to be carried out by changing the relative position of the core.

2. Toroid

The toroidal or " ring "—core may be considered as a long solenoid which is bent round into a ring and joined up to form a continuous core. This type has the advantage that, by placing the winding in close proximity to the core, the external leakage field can be made very small. This means that the effective permeability approaches that of the material and also enables the coil to be surrounded by a closely-fitting screening-can without introducing excessive losses.

Toroidal cores are used at relatively low frequencies where the maximum effective permeability is required; a typical application being to loading coils for telephone circuits. The fact that the full permeability can be closely approached leads to the use of toroidal test cores for the accurate measurement of the specific permeability of core materials and also for the experimental investigation of core losses.[6] One disadvantage of the toroid is the difficulty of applying the winding, since this cannot be wound on a bobbin and then slipped on to the core as with other types. Special winding machines have been designed for winding toroidal coils, but these are limited as to the range of wire gauges and the sizes of cores which can be dealt with. Another disadvantage is the difficulty of obtaining an accurate final adjustment of the inductance value, particularly when the winding consists of only a few turns of wire.

3. Ironclad or " Pot " Core

In this type the core is extended until it completely encloses the bobbin. There are several versions which differ mainly in the way in which the core is split in order that the bobbin can be inserted. A central hole is usually provided for adjustment of inductance, which can be carried out either by placing a suitable piece of material in the hole and sealing it in position, or by means of a plunger attached to a screwed rod as described above. A range of adjustment of about 10 per cent. of the total inductance can be obtained in this way. This type of core combines the advantages of a fairly high effective permeability with ease of construction and adjustment, and it is extensively used at medium and high frequencies.

4. " Cotton-reel " Core

The shape of this core is explained by its name. It may be regarded as an intermediate stage between the simple open solenoid and the closed " pot " core, since it has a central core (which may or may not contain an adjustable plug and two flanges) which give the complete core a " cotton reel " shape. As in the case of the " pot " core there are several versions which differ in the way in which the core is split to enable the bobbin to be assembled.

5. " E and I " Core

This takes the same form as the familiar laminated core. It is simple and easy to construct, but its low effective permeability make it suitable for higher frequencies only.

6. " L " Core

This is merely a variation of the above type which requires only a single mould to form the two parts of the core. It has an even lower effective permeability. Both the " L " and " E-and-I " cores cannot be adjusted and are often used in transformers for use at radio frequencies.

Dimensions of Cores

It will be shown later that for the best results, the power losses due to the resistance of the winding and the eddy currents in the core should be approximately equal. At low frequencies the main problem is to keep the winding resistance down, so that cores tend to be massive in order to obtain the necessary winding space. At high frequencies the reverse is the case and the cores are kept as small as possible to reduce the eddy current losses. As a result, cores are made in many different sizes, ranging from toroids several inches in diameter down to tiny solenoids which may be only a fraction of an inch in length and diameter.

The table which follows gives some idea of the way in which the frequency spectrum is covered by the various types of core. The frequency ranges have been deliberately left vague because no definite limits can be set :

Freq. Range	Material	μ	Core Type	μ
Power (<100 c/s)	Laminations			
Speech (100 c/s—10Kc/s)	Permalloy Dust	100	Toroid	100
Carrier (10Kc/s—500Kc/s)	Iron Dust	20	Toroid	20
			Pot	6
			E and I	4
		12	Pot	5
			Cotton-reel	4
Radio (>500Kc/s)	Iron Dust		E and I	3
			L	2
			Solenoid	1
	Air Core	1	Solenoid or " Slab "	1

Bibliography

1 Speed and Elmen, *Trans. A.I.E.E.*, 1921, p. 1321
2 Shackleton and Barber, *Trans. A.I.E.E.*, 1928 p. 429.
3 Hans Vogt, *Wireless World*, 1932, p. 272.
Schneider, *Electrician*, 1934, Dec. 14.
4 Chasten, *Elec. Comm.*, 1935, p. 142.
5 *Elek. Tech. Zeitschr.*, 1937, Dec. 23.
6 Welsby, *P.O.E.E.J.*, 1942, p. 46.

Robert W. Paul

Pioneer Instrument Maker and Cinematographer

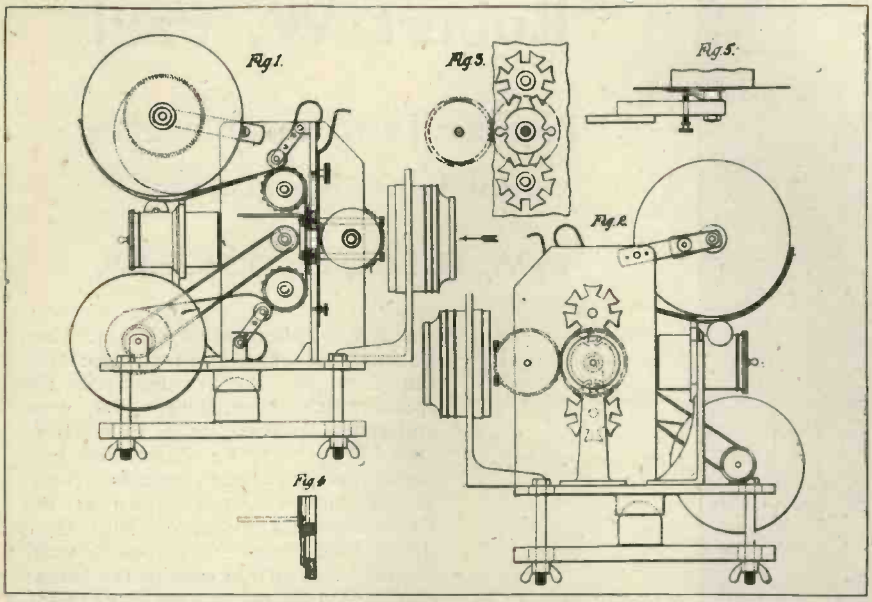
By W. H. ECCLES, D.Sc., F.R.S.

ROBERT WILLIAM PAUL was born at Highbury, on October 3, 1869, and died in London on March 28, 1943. His father was a London shipowner, whose ships sailed out of the Pool of London to the Baltic and the Levant. He was educated at the City of London School and at the City and Guilds of London Technical College, newly opened near Finsbury Square. During vacations he took long trips on his father's ships and acquired a taste for travel that endured throughout his life.

At Finsbury Technical College he excelled on the electrical side and discovered his abilities for electrical and mechanical design. After leaving college he went to Elliots to learn instrument-making and also to the factory of the Bell Telephone Company at Antwerp. In 1891 he started his own business as an instrument maker in small premises in Hatton Garden. He kept up his contacts with Finsbury Technical College by getting the teachers there to suggest and partially design instruments. In this way he made instruments outlined by Ayrton, Perry, Mather, Sumpner, Walmsley and others. His personal contribution to the designs at this date was mainly on the mechanical side, for which he early showed great ability. Many of the instruments that spread all over the world bearing the above famous names owed much of their practical and commercial success to Paul's genius for soundness in mechanical design and workmanship. It is a striking fact that his business expanded so fast that the works he started in Hatton Garden in 1891 had to be augmented by a four storey factory in Great Saffron Hill close by in 1894.

Now in 1894 two Greek showmen brought from America to London one or two of Edison and Dickson's new Kinetoscopes. Charging twopence a time for a peep through an eyepiece at the short "living picture" given by a film of 40 feet arranged as an endless belt, the showmen had difficulty in dealing with the crowds that besieged their shop near Liverpool Street station. They sought out Paul and asked him to make six similar instruments; this was permissible as Edison had not patented it this side of the Atlantic. During the next year Paul made sixty more with improvements. As the American originators naturally refused to supply new pictures for use in these machines, Paul started from scratch on the design, manufacture and use of cameras for taking pictures. He was thus the first cinematographer in this country. Then he designed a machine for perforating the film so that it engaged the sprocket wheels without undue wear and tear. At each stage, it has been stated by users, he introduced new ideas and great improvements. Some of his pictures were shown at the Earls Court Exhibition of 1895. Here the sight of the queues of people waiting for their turn at each of the fifteen machines on show, roused Paul to the endeavour to project living pictures on to a screen, a feat as yet unattempted or, at any rate, unachieved.

The principal difficulty was to give the film a step-by-step motion such that it was standing still for a large fraction of the time, for only thus could sufficient light be transmitted through each picture or "frame" in turn. He worked at the problem with great energy and towards the end of 1895 he obtained success with a mechanism consisting of a finger wheel rotating uniformly which engaged with slots in a star wheel. This is on the same arbor as the sprocket wheels, moves forward one frame-length at each engagement with the finger wheel and is held stationary between whiles. Embodying this in a form which could be attached to the standard pattern of lecture lantern he was then manufacturing, he fed the intermittently moved film from a spool through the stage of the lantern and collected it in a basket beneath. The light was made suitably intermittent by an oscillating shutter which, through gearing, opened each time the film came to rest. With this first machine he gave a demonstration at the Finsbury Technical College Conversazione on February 20, 1896. As it happened the Lumiere Brothers, who had been working independently at the same problem in Paris, gave an exhibition with their projector at the Regent Street Polytechnic the same evening. Paul patented his projector on March 2, 1896 (patent No. 4686). This patent covers in particular the star wheel with slots, now called the Maltese Cross intermittent motion, which is to-day universally used, having driven nearly all rivals off the market.



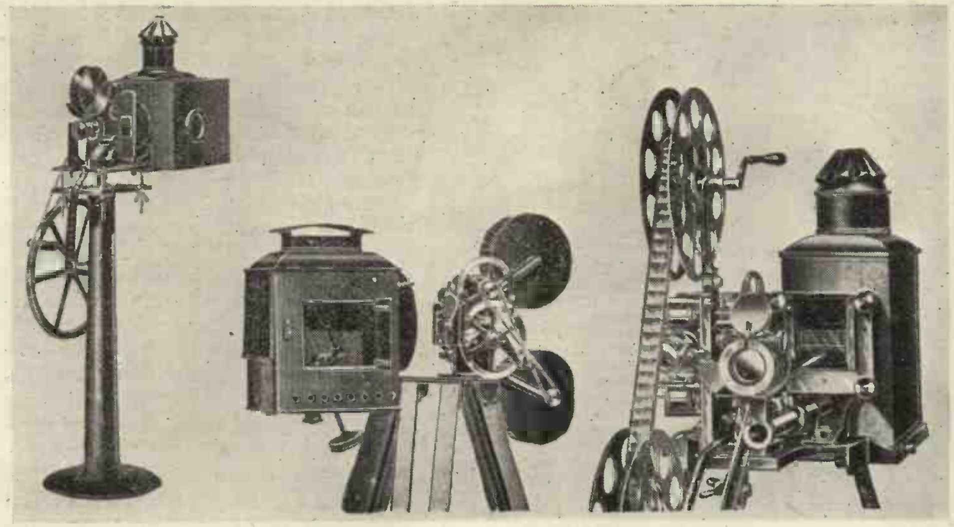
Drawings from Paul's Patent Specification showing the Maltese Cross Mechanism (Pat. No. 4686, 1896).

Paul now began to receive pressing invitations to give a show at various public places. For instance he was engaged by the Alhambra management to give an item in the evening programme lasting ten minutes. The engagement was for a fortnight only as everyone knew that the public would soon get tired of living pictures, even under the new name of the Animatograph. To test the public taste, however, a short playlet was staged on the flat roof of the Alhambra and "shot" by Paul. It was called "The Soldier's Courtship," occupied 80 feet of film and was a roaring success. In the making of this film Paul met his future wife, who comes of an old theatrical family, and who played the principal character. With amazing energy Paul also shot topical events, for instance the Derby of 1896 when the Prince of Wales's horse Persimmon won the race. On the following day the film was shown at the Alhambra in the presence of the owner. The public enthusiasm was overwhelming; Paul was called before the curtain many times and received a great ovation. Of course by this time the original two weeks engagement had been exceeded; actually it extended itself two years.

An obvious result of these striking proofs of popularity was that a great demand arose for projectors and finished films. It came from every European country, from Kings and from professional entertainers, from variety theatres and fair ground showmen. He therefore enlarged his factory and engaged a staff of photographers. The office and works were besieged by would-be purchasers speaking every language, who waited impatiently for equipment and meanwhile took lessons in a school for operators which Paul improvised. Over a hundred projectors were sold at a price of £80 each in twelve months—and when cameras, films at ninepence per foot, and fees earned by shows, were added into the account the turnover was £18,000. Paul had accomplished this without borrowing any outside capital; it grew out of his own few hundreds with which he started his instrument works in 1891. But as business was expanding so rapidly he and some friends tried to float a company to take over the cinematograph side of his interests, patents and all. It was a fine opportunity for the public to get in "on the ground floor" of the vast cinema industry of the future. But the subscription was so small that the company did not go to allotment. The cautious investing public did not believe in "living pictures."

During 1897 a fatal fire at a cinema demonstration (not Paul's) in Paris made him redesign his projector so as to be encased in sheet steel and the film after passing through the projector was wound on an internal spool. Various troubles in driving this spool were admirably overcome. Meanwhile he frequently headed his photographic staff when shooting topical events, and always did the evening round of some half dozen London music halls where he had a turn. Nevertheless he found time to develop new electrical instruments and improve old ones for use in university laboratories and in industry. In 1897, also, he found time to get married. Thereafter his wife was producer, stage manager or principal lady in many a playlet for which her expert knowledge eminently fitted her. In the same year he bought a field at Muswell Hill for the erection of a special studio—the first of its kind in Europe. It comprised a miniature stage, a movable hanging bridge, many trapdoors, a trolley system for running the camera to and fro at speed, and means for turning the camera accurately on its axis. There was also a scene painting room, where, at first, Paul himself painted all the scenery at night "after the day's work was over" as he said. Actors from the London theatres came to the studio to play their parts. Gradually, at this studio the "trick film" was developed; ghosts, ogres, fairies, dwafts and giants became everyday products. Deep sea divers found boxes of treasure with live fishes apparently swimming round them. A very great success was a collision between two trains on an embankment beside a lake; this was so realistic that the audience usually screamed. It was pirated in many countries, especially in America, as sale of the film in London was outright. A great authority on the history of the cinema has said "Paul's trick films were the first and best of their kind in England and

Original Maltese Cross Mechanism incorporated in a film projector.



The Development of the Animatograph.

An illustration from an early booklet issued by Paul, describing his 'machine for projecting pictures in the most perfect manner.'

three such research instruments for high frequency that the writer first met Paul.

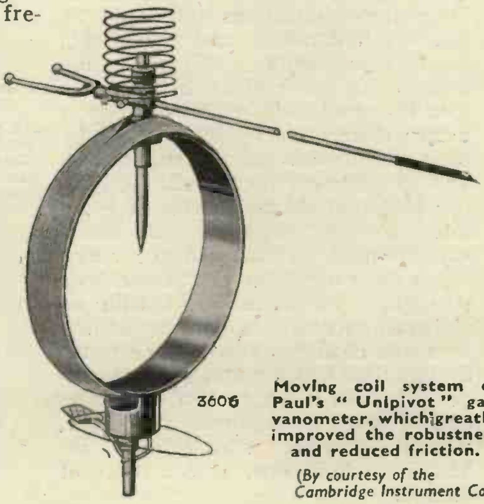
In 1904 his instruments were awarded the gold medal at St. Louis, and in 1910 the gold medal at Brussels. In this latter year he made up his mind to drop the cinema department, which he had always called a "side-line," and to concentrate on instrument making. He burned his large stock of film and disposed of the special plant. He then laid out his works for the more intensive production of electrical instruments with the result that output was rising fast in 1913-14. The war caused the demand for testing and measuring instruments to come mostly from government departments during the next four years. Paul's personal contributions to new devices included suggestions and models for acoustic mines and magnetic mines, and the apparatus for the location of mines and submarines. And, of course, his factory turned out a great volume of testing instruments needed by the Services. At the end of the war an amalgamation with the Cambridge Scientific Instrument Co. was arranged. Thereafter Paul gradually withdrew from the drawing office and the factory and concerned himself more with the finance and economics of the industry. And he took up again his reading of classical and modern literature in which he was very well grounded.

Although semi-retired, his constructive energy surged up strongly if a practical problem were put before him. In response to one suggestion

eclipsed anything produced throughout the world."

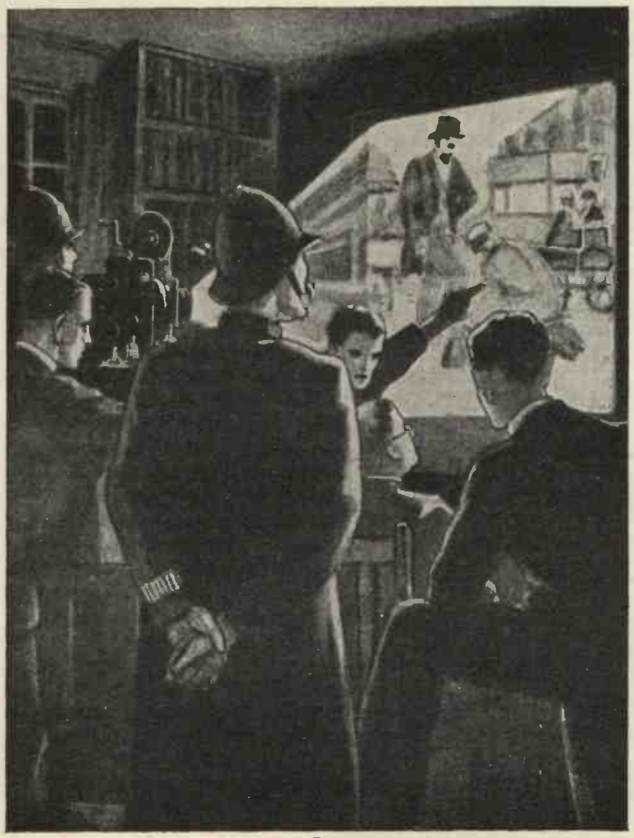
In 1898, feeling that the amount of light passed by his existing intermittent motion and shutter was less than it might be, Paul invented and developed an ingenious improvement which is described in patent specification No. 487 of 1899. It eliminates jerkiness in the motion and is capable of working at high speeds. He also developed a high speed camera capable of taking 120 pictures a second. This was employed by Vernon Boys for making slow-motion photographs of sound-wave shadows. It was also used by Worthington for making pictures of the splashes produced in a still water surface by falling objects. Another set of historic scientific films was made in collaboration with Silvanus Thompson, who made the necessary numerous drawings for illustrating the motion of lines of force in changing magnetic fields. This last led to the making of cartoon films—a long-distance forerunner of Walt Disney's present-day speciality. By this time the amount of film Paul was processing for public exhibition was about 8,000 feet a day.

Although the cinema side of his business was rising to a profitable crescendo between 1905 and 1910, Paul resented the fact that it distracted him from electrical instrument making. But this side was also growing. He was a master of design and his instruments were distinguished by their mechanical as well as electrical qualities. About 1903, in the midst of the rush of work described above, he invented the famous "Unipivot" table galvanometer. The conventional instrument had a cylindrical iron core fixed between the jaws of a permanent magnet for the purpose of concentrating the field and had a cylindrical moving coil carried by top and bottom pivots so that its sides moved in the spaces between the core and the jaws. The new uni-pivot form of instrument had a spherical iron core fixed between embracing jaws and had a circular moving coil. There was a vertical hole drilled from the top to the centre of the sphere and the single jewel was fixed at the bottom of this hole very accurately centred. An inward radial spike starting from the top of the coil rested with its pivot-point on the jewel, and control was obtained by two external helical springs carrying current in and out of the coil; the coil and its attachments were accurately balanced to bring the centre of gravity to the pivot point. This construction besides its advantages in use permitted the clamping of the movement for transport; frequently this clamping was arranged to be done automatically as the instrument was lifted off the table. This design eliminated levelling, reduced friction, and deservedly became a great commercial success. From 1905 Paul reduced his attention to the cinema and developed instruments suggested or invented by Campbell, Darling, Duddell, Drysdale, Irwin, Jolley, and others. Many of these instruments sold well; indeed he had to set up a branch works in New York in 1911. But he frequently assisted research workers by building non-such instruments of a kind never likely to sell. It was in connexion with two or



Moving coil system of Paul's "Unipivot" galvanometer, which greatly improved the robustness and reduced friction.

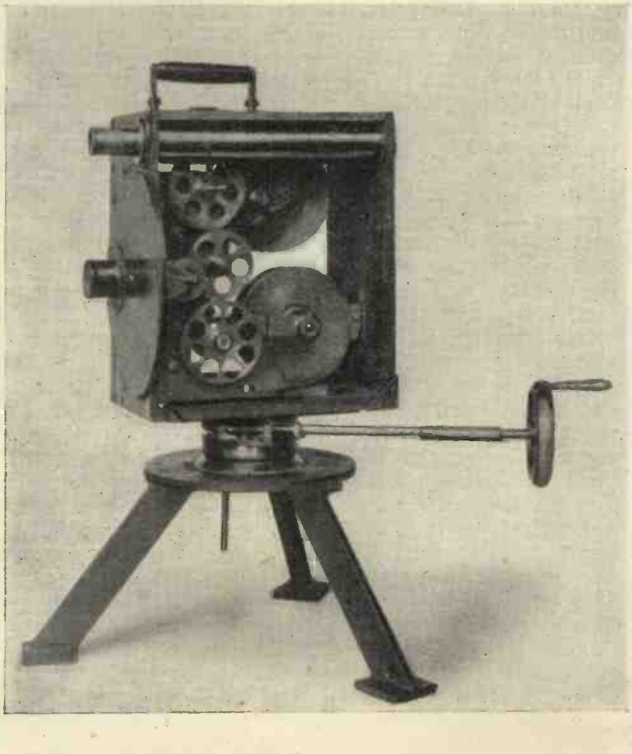
(By courtesy of the Cambridge Instrument Co.)



" England produces the first moving picture on screen " . . . it was in London in February, 1895 that the first moving picture was thrown on a screen. About 3 a.m. policemen in Hatton Garden heard shouting, and running to a studio found Robert Paul and his workmen shouting with delight at having successfully thrown a clear moving picture on the screen for the first time.

he equipped his car with an excellent forced ventilating system; he also designed and made a very neat non-electrical petrol gauge. He entered the loud speaker field with the new idea of a diaphragm of balsa wood. When Sir William Bragg placed before him the problem of keeping the lungs of a paralytic friend going, Paul produced a machine, which he called the " pulsator," which has since been made by the dozen for hospitals. Again, when the Faraday Centenary Exhibition was planned he offered to make up replicas of early apparatus from the descriptions published by Faraday and others, and produced a magnificent display. All these and many other mechanisms he made up with his own hands in his workshop at home; there is no doubt he was happiest when he was constructing things, and constructing them well. All his life he hated clumsy work. It is related that on going round the works one morning he came to the bench where quite a good workman had been struggling for some weeks with an elaborate recording apparatus, adding here and changing there. The result by this time was a mess; so Paul suddenly picked it up, took a big swing and threw it against the wall. " Now," said he, " start again." He had, it reminds one, a keen sense of humour.

The story of Paul's life would be very incomplete if his charitable acts were forgotten. Many of these were never disclosed fully even to close friends. Others, such as supporting individual research workers who for a while had fallen on hard times, came to one's knowledge accidentally. Other public spirited actions are known more widely. For example he organised and financed the Apprentices' Prizes at the Physical Society's Annual Exhibition of Apparatus. He founded a Scholarship which is awarded by the Institution of Electrical Engineers. To this Institution he presented a beautiful painting of Volta, and to the Franklin Institute of Philadelphia he presented a full size replica of Faraday's statue in the Royal Institution, London. But his reserve and shyness and a kind of talent for fading away unnoticed were exceptional. For instance, probably no voluntary worker did nearly as much for the Faraday Centenary Exhibition as did Paul; but in the long list of acknowledgments to persons who helped the Exhibition, even by attending a sub-committee meeting, the name of Paul does not appear. Again, many of those who knew how great he was in the world of the cinema did not know of his contribution to applied physics—and vice versa. For these reasons, possibly, few honours came his way. Two he appreciated greatly were the Vice-Presidency of the Physical Society and the Duddell Medal of 1938. When more is known of his benefactions, it will be recognised that he was a great philanthropist, as well as a great leader in the applications of science.



Paul's Cinematograph Camera (1896).

This machine was used by Paul for filming Queen Victoria's Jubilee in 1897, for which purpose a special stand was designed.

Physics and the Static Characteristics of Hard Vacuum Valves

by J. H. FREMLIN, M.A., Ph.D., F.Inst.P. *

A Paper read before the Electronics Group of the Institute of Physics on April 6th, 1943, at the Royal Institution.

THE characteristics of hard valves have been considered in detail by many hundreds of people for a large part of their working lives. It is likely, therefore, that I shall omit all mention of many points that seem to some to be of outstanding interest.

I propose to confine myself mainly to the most essential valve properties and shall not say much about secondary emission for example, or anything at all about such things as contact potentials, cathode coating characteristics, grid emission or especially, noise.

Now the physical laws involved in hard valve design are mostly known to adequate accuracy. The problems lie largely in the application of well known laws to complicated systems. This is not always easy. In order to get results of practical value it is often necessary to make drastic approximations. By this I do not mean merely that we have to consider theoretically structures that are much simpler than those in which we are really interested. We have also to employ physical concepts which are known to be incorrect, in the not invariably misplaced hope that the errors so introduced will be negligible, and the success of the physicist in valve design depends less on his knowledge of the details of natural law than on his knowledge of when any such laws may be neglected with impunity.

Thus, most elementary theory of thermionic valves can proceed quite adequately on the assumption that current as well as potential distribution is continuous through space. Knowledge of the particulate nature of electricity, which was gained before 1900, is not used and is, except by those who have the courage to work on the vexed question of noise, often effectively banished from mind. I hope to give here some indication of the limits within which such simple conceptions are useful. These limits are surprisingly wide and it is to me very striking that we even now only occasionally need to advance from the continuous fluid theory of electricity to the particulate theory and that the further advance to the higher forms of continuous function provided by wave mechanics seems unlikely to be called on extensively for a while yet.

Now from a practical viewpoint the characteristics of a valve may be regarded as the relations determining the currents to the various electrodes of the valve as a function of the voltages supplied to these electrodes.

Consider first the simplest type of valve, the diode. It has been shown by Langmuir[1] that the current in space charge limited conditions will always be proportional to the three halves power of the voltage, whatever the shape of the electrodes. This has been shown to be true still more generally by Wheatcroft, using the method of dimensions, for all cases in which the velocity of a current element at any point is proportional to the square root of the potential at that point. This criterion will cover certain forms of gas discharge as well as hard valves. The range of validity of this argument is not, however, quite clear. I cannot see how the required limitation to space-charge limited conditions comes in.

The constants of proportionality for plane and cylindrical diodes have, as is well known, been calculated by Child and Langmuir. The physical laws involved are solely those described in the fundamental definitions of charge and potential, as expressed in Poisson's equation $\nabla^2 V = -4\pi\rho$ together with the Newtonian laws of mechanics. The way in which the proof is written out usually obscures the fact that a particulate theory is unnecessary so long as the ratio of charge to mass of electricity is correctly included.

Some difficulty is sometimes found with the assumption of zero emission velocity on the grounds that in this case there will be no emission at all with zero or negative field at the cathode and saturated emission with the smallest positive field. This difficulty is, however, merely the familiar one of determining by inspection the value of $\frac{0}{0}$. In fact, the emission with zero field and zero emission velocity is indeterminate in the absence of further information; it is quite incorrect to say that emission is obviously zero. Its value depends upon the space charge considerations given by Child and Langmuir, for if the current fell below their calculated value a positive field would exist and full emission would occur till space charge between anode and cathode just neutralised the field, while if the current were too great a negative field would occur and the current would cease entirely until this field had vanished. The indeterminacy is, therefore, resolved by the fact that any current differing by a finite amount from that calculated is quite certainly not in equilibrium.

For an infinite parallel plane diode with anode cathode distance d we have the current density i_a given by

$$i_a = \frac{2.34 \times 10^{-3}\, V_a{}^{3/2}}{d^2} \text{ mA/sq. cm.}$$

for zero emission energy. A similar formula for the current per unit length in an infinite cylindrical diode is also obtained. For reasonably large voltages these formulæ hold satisfactorily up to the largest current densities which the cathode can give without saturation. For small voltages, even if allowance is properly made for contact potentials, the current is found in experimental tubes to be persistently larger than predicted by the Child-Langmuir formula, and current actually continues to flow when the anode is at a slightly negative voltage. We can, however, say that experiments on diodes have shown that over a wide range it is not usually necessary to take account of the particulate nature of electrons and can therefore proceed with some confidence to neglect it in our first consideration of more complicated valves. While neglecting it we must not, however, forget it.

Consider now the triode. Even with the drastic simplification suggested it is not possible to solve Poisson's equation for the boundary conditions existing in an ordinary triode. It is difficult even to write down what the boundary conditions are until we have left out the grid supports and insulators and considered an infinite parallel plane or cylindrical system to eliminate all edges and ends. With the austerity triode thus produced, we can write down the conditions, but we still cannot solve the equations. Resort is usually made, therefore, to a subterfuge. The system usually employed is to determine, by intuition or otherwise, the dimensions and electrode potentials of a diode, "equivalent" to the triode with which we are concerned, in terms of the geometry and electrode potentials of the triode. The meaning and means of determining

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"equivalence" merit some discussion. It is clear that, to the approximation previously decided upon, the current emitted in each valve must be such as just to reduce to zero the normal electric field at the cathode surface. It is often stated, therefore, without more ado, that the equivalent diode is simply a diode which in the absence of space charge has the same electric field at the cathode surface. Now the electric field at any point on the cathode of a triode can normally be found, and is found to be a linear function of the grid and anode voltages V_g and V_a respectively. If the cathode is far enough from the grid for the electric field at its surface to be uniform, it may be written

$$\frac{V_g + DV_a}{l_g + Dl_a}$$

where D is a function of the grid geometry and position which we shall call the "penetration factor"; l_g is the distance between grid and cathode and l_a the distance between anode and cathode. Any diode with a cathode-anode distance $K(l_g + Dl_a)$ and anode voltage $K(V_g + DV_a)$ would give this cathode field. We can, of course, define equivalence in any way we like, but if, as is normally the case, we wish to use the diode to forecast the current density in the triode, we must not assume that all such diodes will require the same current to neutralise their admittedly identical cathode fields. This is clearly not the case; if we look for a moment at Child's equation,

$$i = \frac{2.34 \times 10^{-3} V^{3/2}}{d^2}$$

we see that it can be written as

$$i = \frac{2.34 \times 10^{-3} E^{3/2}}{\sqrt{d}} \text{ mA/sq.cm.}$$

where E is the normal cathode field in volts/cm., and this clearly depends upon d as well as upon E. We have, therefore, to find some further criterion to tell us which of the infinite series of possible diodes to use. There is no prior reason for assuming that the same distance may be chosen for all currents but there is experimental evidence that current is proportional to $(V_g + DV_a)^{3/2}$ in a plane triode, so we shall add one more to our list of assumptions by supposing that the diode distance l_d is independent of the voltage. We can then find[2] what the distance is quite readily by considering the potential distribution in the triode when the grid is positive at such a potential as to be itself uncharged, when, of course, the potential is $al^{4/3}$. Hence

$$l_d = l_g \left\{ \frac{1 + D\left(\frac{l_a}{l_g}\right)^{4/3}}{1 + D\left(\frac{l_a}{l_g}\right)} \right\}$$

and from this we find the total emission current density

$$i = \frac{2.34 \times 10^{-3}(V_g + DV_a)^{3/2}}{l_g^2 \left\{ 1 + D\left(\frac{l_a}{l_g}\right)^{4/3} \right\}^{3/2}} \text{ mA. per sq.cm.}$$

Now there is no theoretical justification for the supposition that there exists at all an equivalent diode of invariable dimensions. In fact, it has been pointed out by Rodda[3] and by Dow[4] that such a diode is certainly non-existent. The analysis which I have given assumes that D remains constant, which is untrue if space charge exists between grid and anode, and Rodda gives a formula allowing for the variation of equivalent diode dimensions with voltage which for large current densities and large grid-anode spaces gives appreciably different results from the formula which I have given above. I think, however, that the non-uniformity of current distribution in the grid plane, which has been neglected in both formulæ, may well be as important as the differences between them. In many cases, as Dow has pointed out, it is quite accurate enough to take the equivalent diode distance simply as $l_g + Dl_a$. As in the case of the diode, this formula breaks down for very small emission current densities; it has also an extra and independent condition in which breakdown occurs, *i.e.*, when V_g is positive and V_a is small or negative. This is quite apart from the effects of secondary emission.

I want now to go back a little to say something about the determination of the penetration factor D in the absence of space charge, which is necessary before any of the triode formulæ can be used. Apart from mathematical methods, which I do not intend to discuss here, it is possible to do this in many cases by the use of mechanical models, particularly by the use of a stretched membrane in a state of uniform tension as proposed by Dr. Moon—hereafter referred to as a rubber sheet—or by an electrolytic trough. As I have worked myself with the former[2] and as I shall want to mention it in other connexions, I will describe shortly its main properties.

If the sheet is stretched tightly in a horizontal plane and if points on it are then slightly displaced vertically by suitably applied pressure, any points on the free parts of the sheet will conform to the equation

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0$$

where h is the vertical displacement of the point from the horizontal plane containing the co-ordinate axes of x and y. This equation is of the same form as Laplace's equation for a potential distribution independent of the z axis, the displacement h taking the place of the potential. We can then determine the form of the potential distribution for any system of electrodes whose geometry varies only in two dimensions by applying models of such electrodes to the stretched sheet, their displacements being proportional to the potentials intended to be carried by the electrodes. The slope of the rubber sheet at any point, for example at the edge of the "cathode" model, will then be proportional to the electric field at the corresponding point in the real valve. We can therefore measure D quite easily by measuring the height through which it

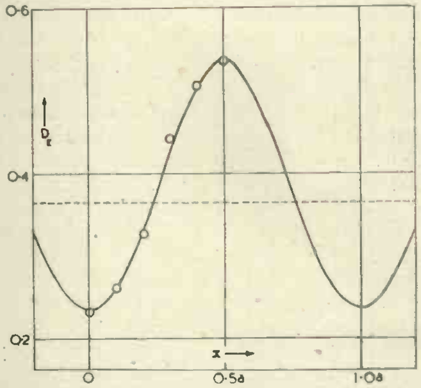

Fig. 1. D_E is the electrostatically calculated value of the penetration factor at a point on the cathode surface. The curve shows the variation of this according to theory with the distance x measured from a point immediately below a grid wire. The points ⊙ were obtained experimentally on the rubber sheet model. The dotted line shows the value of D obtained from the Schottky-Miller formula.
$d = 0.0322a$, $l_g = 0.40a$, $l_a = 1.40a$

is necessary to move the grid model to compensate exactly the effect, on this slope at the cathode, of moving the anode model through one unit of height. A small piece of mirror attached to the sheet and reflecting a spot of light on to a fixed scale gives a convenient and sensitive method for detecting small changes of cathode field.

This method has been used to check a calculation of the change of D along the cathode when the distance between cathode and grid is small compared to the grid pitch (see Fig. 1), to check a calculation of the effect on D of having the grid-anode distance small compared to the grid pitch (see Fig. 2) and to compare the formulæ given by various authorities for the penetration factor in triodes with very thick grid

wires. Incidentally, the best of these would appear to be that given by Ollendorff which also lends itself conveniently to the construction of a nomogram for its application.

The rubber sheet method has also been applied to the measurement of inter-electrode capacities and again is capable of dealing with cases which are entirely intractable mathematically. To show that the space-charge-free result of rubber sheet experiments may be of practical value, Fig. 3 gives the electrostatically calculated value of $1/D$ midway between grid wires, for small grid-cathode distances, together with the results from a real triode, in which the electrodes were mechanically adjustable.

I think I have said enough to support my claim that D can be determined; for cases which cannot be treated on the rubber sheet, the electrolytic trough may be used.[5,6] We are not yet, however, quite out of the wood. The field at the cathode may not be uniform, either because the grid is too close or because the cathode is in filamentary form; so that every

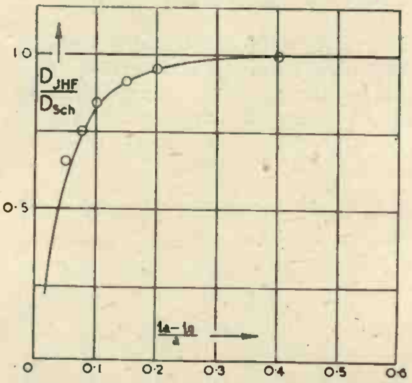

Fig. 2. Variation of penetration factor D_E calculated by electrostatic image theory, from the value given by the Schottky-Miller formula (D_{SCH}), as the grid anode distance becomes small. Points ⊙ obtained from the rubber sheet model

point of the cathode would appear to require its own private equivalent diode. When the grid is too close we can for small current densities use the calculable cut-off value of penetration factor,[2] but for larger currents the mean amplification factor increases rapidly and the current may increase far more rapidly than would be suggested by the inverse square law.

When the cathode is filamentary we can most conveniently assume it to be flat with an "effective area" dependent more upon the distribution of filament limbs than upon their own surface area; I must confess that I do not know of a satisfactory general method for determining this "effective area" except by direct experiment.

Now the difficulties which I have mentioned so far are not physically very important. That is to say, they are difficulties due mainly to complexity of detail rather than to inadequacy of the physical laws assumed to hold. If I shot a bucket of assorted ball bearings down a flight of steps, my inability to determine their exact tracks by calculation would not be materially affected by my using Einstein's laws of motion rather than Newton's.

The simplification of assuming the space current in a valve to behave like a uniform fluid is quite close enough to the truth within limits. I propose now to consider these limits a little more closely. I think that we shall be able to see that many of them will be pushed back a very considerable distance by taking into account our physical knowledge of the particulate nature of electrons.

It has been known for many years that when the voltage on the anode of a diode is reduced to small values, the three-halves power law is not obeyed and that current continues to flow, falling off exponentially with anode voltage, even when the anode is negative with respect to cathode. This may readily be explained on a particulate theory, on the assumption that electrons are emitted with random energies distributed according to the normal Maxwellian laws where the number having energy greater than any given value eV falls off as $\varepsilon^{\frac{-eV}{kT}}$. We can get an immediate check on this by looking at the magnitudes involved; thus experimentally, the energies of the electrons would have to be of the order of tenths of a volt to explain the observed effects. If we take the energy as corresponding to 1/10 volt, or 1/3,000 ESU, the energy of the electron will be $e/3{,}000$. This must, if the hypothesis be true, be of the order kT where $k = 1.4 \times 10^{-16}$ and T is, say, 1,000° Abs. Hence e must be of the order $1.4 \times 3 \times 10^{6} \times 10^{-16}$ or 4×10^{-10} ESU, which is, of course, in adequate accord with our knowledge of the electronic charge. Thus we are able to use the improved physical theory to give a quantitative explanation of an effect which could not even be qualitatively explained by the more elementary laws previously supposed. For exact calculation of current in a diode we turn again to Langmuir.[1]

This point is of importance in triodes as well as in diodes. The simple theory suggests that we could make a triode of infinite slope if we could only make grids of fine enough pitch and put them close enough to the cathode. Consideration of the uniform nature of the current soon shows, however, that the engineer may not be required to make grids of 1 μ wire 5 μ from the cathode, which will no doubt prove a great disappointment to him. There will in fact be a limiting slope which will not improve as the spacings are reduced, but will depend upon cathode temperature alone. For normal present-day cathodes this limit is in the region of 10 mA./v. per mA. It might

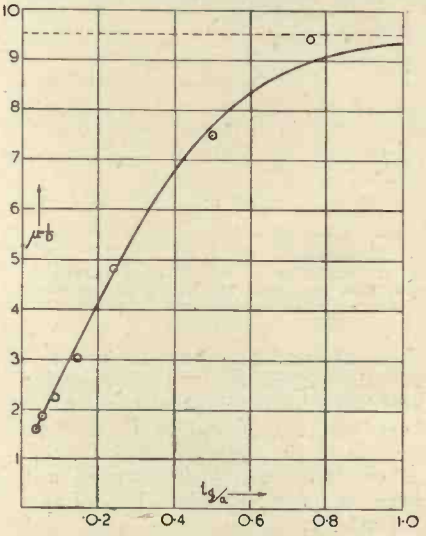

Fig. 3. Variation of penetration factor D and the corresponding amplification factor μ with cathode grid distance when this is small compared to the grid pitch. The curve is calculated from electrostatic image theory and the points ⊙ are the values found near cut-off in an experimental valve $d = 0.005$ cm., $l_a - l_g = 0.539$ cm., $a = 0.155$ cm.

appear, therefore, as if triode design in the future will have to be done by the chemist rather than by the valve engineer though the usefulness of even attainable slopes may be limited by the high corresponding capacity.

Consider next the limitation upon the triode formulæ which I mentioned above, when the anode becomes negative. The total emission current will then be collected by the grid, but will be in nearly all cases several times less than that obtained from the formula. This is not easily explicable on the continuous fluid picture of current, but is readily explained on the particulate theory by supposing that most of the electrons miss the grid wires on their first transit and are reflected back by the anode into the grid cathode space; they may oscillate from one side of the grid to the other a large number of times before collection and thus increase the space charge in the cathode grid space a number of times. This behaviour may be examined very easily by the use of the rubber sheet which I have already mentioned; if the upward vertical displacements are

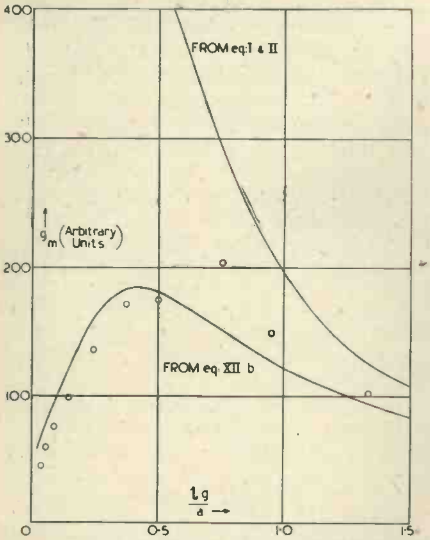

Fig. 4. Variation of mutual conductance gm per unit area with cathode grid distance (The equation numbers refer to Ref. 2).

taken as corresponding to negative potentials it can easily be shown that the track of a small steel ball on the sheet will correspond to that of an electron in the valve, though friction makes long paths inaccurate and space charge cannot be simply allowed for.

Now the cases in which the electron theory is required for dealing with the static characteristics of triodes and diodes are relatively few and to most valve workers of small, though perhaps of increasing, importance.

But when we go on to consider briefly multi-electrode valves the position is markedly changed. The most important characteristics of a pentode, for example, are seriously different from those which would be forecast from the first approximate theory. We can, of course, use the same methods as earlier to calculate the inner and overall amplification factors, and it may be noted in passing that the "inner μ" of a tetrode or pentode is often appreciably different from that calculated for a triode with plate in a position corresponding to the screen in the multi-electrode valve, and is given with very fair accuracy by the formulæ based on electrostatics. (*See* Fig. 5). In a tetrode, the total emission current may also be given by a formula similar to that which I have given for triodes. If we attempt to determine the current distribution between screen and anode, however, we find ourselves often very far from the truth, owing to the "focusing" action of the control grid. The use of the electron theory, with the help of the rubber sheet, enables us to design lined up tetrodes in which the current distribution may be of any type desired.

In a pentode, the situation is a good deal worse still for those who like their currents smooth. Not only is the current distribution between screen and anode only estimable after repeated recourse to the rubber sheet, but the total emission itself is appreciably reduced by the space charge due to electrons reflected by the suppressor. Even more disturbing, the overall amplification factor, which for simpler valves has always been close enough to the electrostatically calculated value, fails us. This is in part due to the increase of space charge as a result of the reflected electrons which I have just mentioned, but it is in much greater part due simply to the change in current distribution between the screen and the anode. The potential distribution between screen and suppressor is considerably affected by the anode potential and, as the anode potential increases, the number of electrons reflected back to the screen decreases with a consequent increase of anode current which is quite independent of any change in total emission. Here again, then, we have a phenomenon which cannot be explained even qualitatively without an understanding of the particulate nature of electricity.

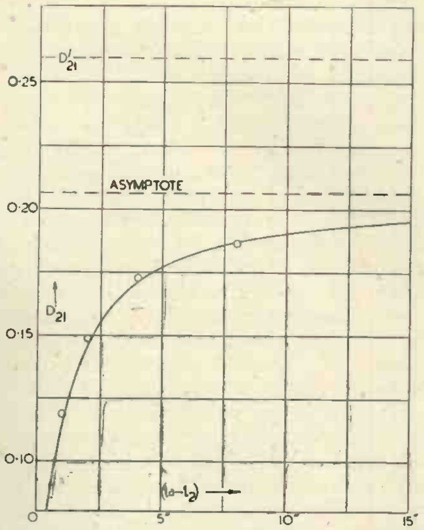

Fig. 5. Variation of inner penetration factor D_{21} with *anode* position in a tetrode.

$a_1 = a_2 = a.\quad \frac{l_1}{a} = 1.25,\quad \frac{l_2 - l_1}{a} = 1.0,\quad \frac{d}{a} = 0.063.$

The dotted line represents the value of D'_{21}, the value calculated for a triode with its plate in the same position as the screen grid of the tetrode. Points ⊙ from the rubber sheet model

As evidence for the explanation which I have just described, Fig. 6 shows the anode current characteristic of a pentode which was obtained by counting the numbers of steel

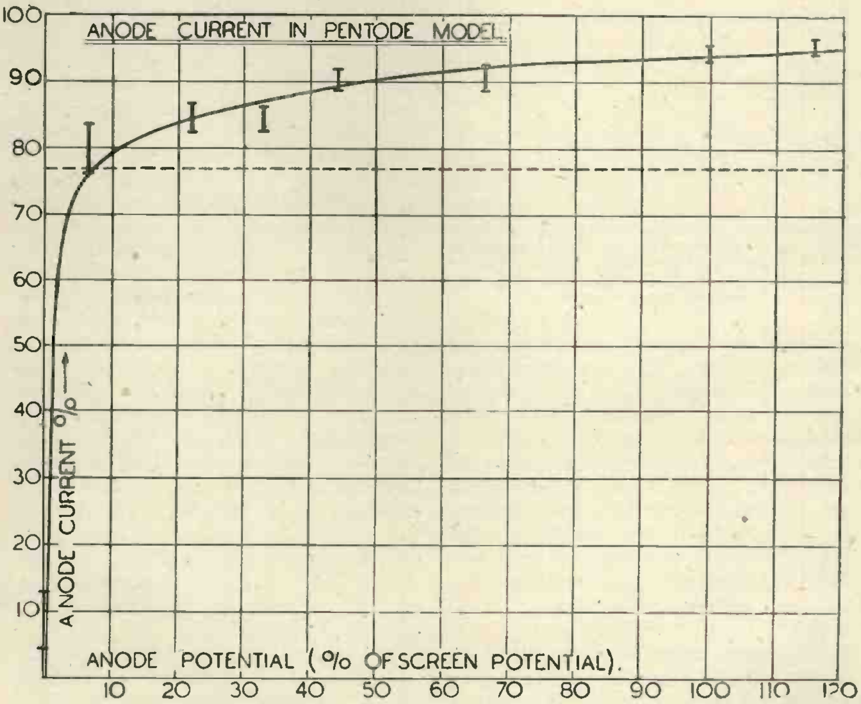

Fig. 6. Variation of anode current, as a percentage of total current, in a pentode model on the rubber sheet (with lined up control and screen grid). The points I were found by observation of the distribution of steel balls between anode and screen; the height of each represents the probable statistical error. The dotted line represents the proportion which would have reached the anode if there were no focusing effect by the control grid and if no reflexion occurred at the suppressor grid

balls reaching the anode of a rubber sheet model. The amplification factor calculated by purely electrostatic means was about 3,300 The effective amplification factor determined from the rubber sheet results depends on the current, but at zero control grid bias it would be 97, or 33 times lower than would be the case if reflexion did not occur. I think it is clear from this why the impedance of pentodes is often lower than that of beam tetrodes and much lower than would at first sight be expected. It seems, too, that the design of suppressor grids merits more attention than has usually been given to them in the past.

A further example of this phenomenon occurs in the pentagrid converter, where the electrons reflected in the outer parts of the valve may seriously upset the proper working of the inner. The reflexion from the suppressor can, incidentally, be turned to good account; in the transitron oscillator a negative resistance independent of frequency has been obtained by its use.

Now I have attempted to show you some of the limits of the very simple theory normally used in consideration of valve characteristics. It is to me always surprising that one can get results so close to reality over such a wide range as one does, when it is realised that in a quite reasonable electron stream of, say, 10 mA./sq.cm. at 250 volts, the average distance between individual electrons is about .001 in., the diameter of a thin grid wire. I have tried to show some of the improvements resulting from the application of the next approximation to reality, and I am looking forward with some interest, not unmixed with apprehension, to the time when this has been sufficiently well worked out to justify the consideration of some of the really very well established non-particulate properties of the electrons themselves.

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5 See for example :—D. B. Langmuir "An Electrolytic Trough for Tracing Electron Paths." *Nature* 139, 1066 (1937, June 17th).

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The Effect of Lightning on Receiving Aerials

Extract from a paper read before the Institution of Electrical Engineers by J. F. Shipley, on *"The Protection of Structures against Lightning"* *

In spite of the fact that the majority of dwelling houses and offices are now equipped with radio receiving aerials, and that these to a large extent correspond to lightning protective systems, although generally of an unsatisfactory kind, the number of cases in which trouble occurs is not of importance.

The author is indebted to Mr. R. A. Price for particulars of some 500 cases of damage to wireless aerials which occurred during the four years ending 1939. The following facts emerge and from them certain conclusions can be drawn.

The number of cases reported was 500. Outside aerials were struck in 405 of them, chimneys or roofs in 79 cases, trees to which aerials were attached were struck in 12 cases, and lightning entered houses by other means in 4 cases.

Of the 405 cases in which lightning struck outside aerials, receiving sets were damaged in 206, house property was damaged in 14, fire was caused in 61, and life endangered in one case only. When the chimney was struck the inside aerials in attics were damaged in 21 cases, and in the remaining cases outside aerials or some other form of conductors were involved. Thirty-five receiving sets were damaged, 12 fires were caused, and there were two cases of danger to life.

There were a few cases of lightning entering houses by means of electric light, telephone or relayed wireless wires, and in one case the earth neutral of the electric lighting system was most probably the route of entry. In one case, 41 receiving sets were put out of order simultaneously. Metal clothes-lines were involved in two cases, and where sets were damaged the electric light system was invariably involved, with small damage to the wiring, switches, meters, etc.

Aerials almost always melted or burned into small lengths when struck, whether they were indoor or outdoor. Indoor aerials when strung in the roof or attic were invariably used as part of the lightning path, with consequent destruction of equipment and danger to property. The down-lead was sometimes melted, but usually formed a jumping-off place for the lightning stroke to damage the building and to set fire to some of the contents. The change-over switch was nearly always useless, whether used as intended or not. There are several accounts of the switch being fused in position, and in one case blown to dust. Earth leads, when traversed by the lightning stroke, were usually melted. Earth connexions were almost always defective, there being many cases of the pipes to which they were connected being damaged, with consequent fire or other trouble. In one case an earth "pipe" was reported as being blown out of the ground. The general opinion formed is that radio earths were unsatisfactory from a lightning-protection point of view.

From the above the following conclusions can be drawn :—

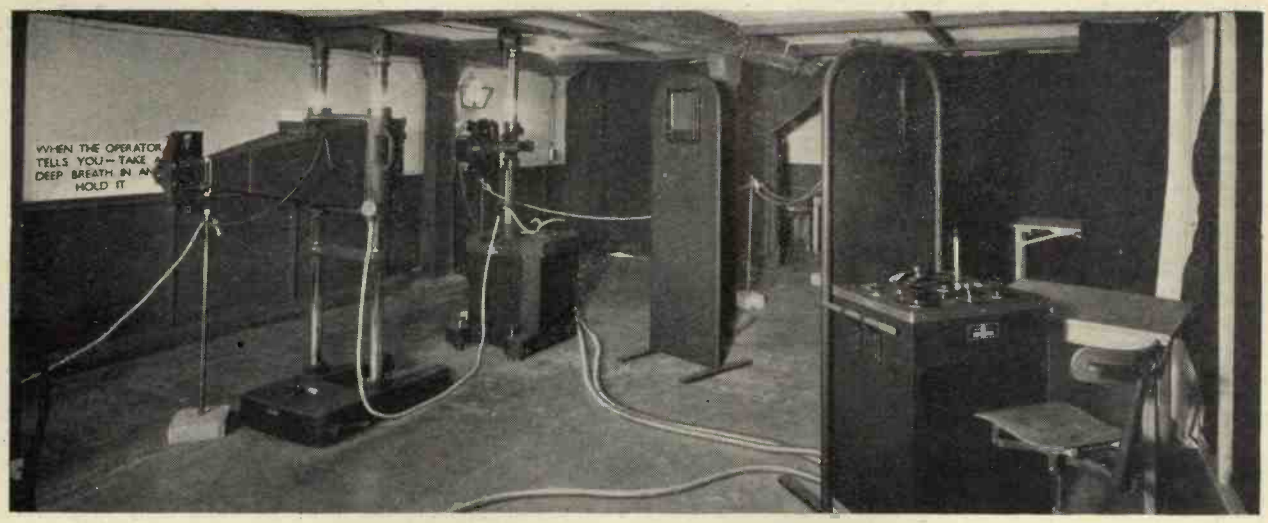
(a) Unless the aerial down-conductor, earth wire and earth conform to the requirements of the new Regulations for Lightning Conductors, cases similar to those reported will occur.

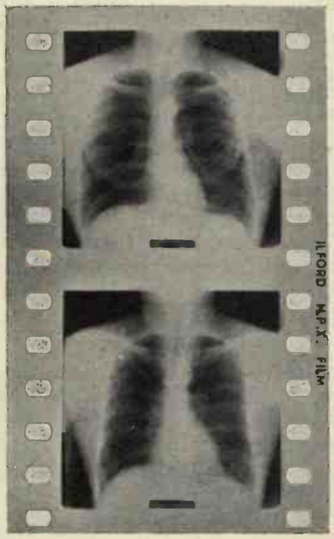
(b) Unless a change-over switch commensurate with the size of down conductor recommended and with much wider isolating gaps, is installed it will be of no use for the protection of the set in a lightning storm. The only use for the normal kind of change-over switch is to discharge the normal earth-air current in fine weather. Beyond this the idea that they provide safety is illusory.

(c) The provision of adequate equipment satisfying (a) and (b) would be uneconomical for the average subscriber. Even if (b) were possible there would still remain the disadvantage that during the passing of the transient flash the set would be raised to an excess voltage which might cause alarm.

(d) The use of a very short aerial in the immediate neighbourhool of the set is recommended to ensure minimum risk from lightning.

* To be published.





Mass Radiography

The photograph at the head of this page shows equipment for mass radiography installed in a large industrial concern for examination of the workers, who attend voluntarily. The tube is of the rotating anode type, withstanding a load of 85 kV. peak at 400 mA. for 1/10th sec. A camera tunnel is mounted on the screen carriage and the patient's identification card is photographed simultaneously with the image. Electrical interlocking ensures that the film is in position and the shutter closed before making the exposure. Considerable experimental data on the essentials for this work has been supplied by Ilford Limited and the apparatus was designed and manufactured in commercial form by Watson & Sons (Electro-Medical) Ltd. Units have also been made by Stanley Cox, Ltd., The Solus Electrical Co., Ltd., and others.

(Left) The subject in place for taking a radiograph. A black cloth cover is worn on the chest.
(Above) Examining films for technical imperfections. Two frames from the length of film are shown at the left of the page.

(Photographs by courtesy of Messrs. Hoover, Ltd., Ilford Ltd., and the Ministry of Information).

DATA SHEETS 51 & 52

Aerial Characteristics and Coupling Systems

Electronic Engineering

THE theory of radiation from an aerial is too complex a subject to be treated in complete detail in this series of Data Sheets. It is therefore proposed to arrange them in the form of notes, providing information on various aspects of aerial performance, and to include a bibliography from which further information can be obtained.

Most of the modern work on aerials in the English language has been published in *The Proceedings of the Institute of Radio Engineers* and to a lesser in the *Journal of the I.E.E.* and on this information the author has drawn freely.

Input Impedance

For the design of matching networks coupling the aerial to the transmitter or to a transmission line, it is essential to know the input impedance of an aerial at its drive point.

However much it may offend the purist, a useful (if only approximate) picture of the change of input impedance with aerial length may be obtained by considering the simple aerial as an open circuited transmission line (*see* Fig. 1). If we let Z_i be the input impedance and Z_o the characteristic impedance of this transmission line, then by normal transmission line theory

$$Z_i = Z_o \coth (\alpha + j\beta)l \quad \ldots \quad (1)$$

where $(\alpha + j\beta) = P$, the Propagation Constant

and α = Attenuation Constant of the line

β = Phase Constant of the line

l = Length of line.

If we write L_o, C_o, R_o, G_o, for the inductance, capacity, resistance and conductance per unit length of line respectively, then when $\omega L_o \gg R_o$ and $\omega C_o \gg G_o$ (as is usually the case with short aerials).

$$\alpha = \sqrt{\tfrac{1}{2} R_o G_o} \quad \ldots \quad (2)$$

$$\beta = \omega\sqrt{L_o C_o} = 2\pi/\lambda \; c\sqrt{L_o C_o} \quad (3)$$

$$Z_o = \sqrt{L_o/C_o} \quad \ldots \quad (4)$$

as $\lambda f = c = 3 \times 10^8$ metres/sec.: the velocity of light. Now the velocity of propagation (v) of a wave along a low loss line is (ω/β) so

$$v = \frac{1}{\sqrt{L_o C_o}} \quad \ldots \quad (5)$$

and if we neglect the retardation of the wave along the wire, that is, make $v = c$, then $\beta = 2\pi/\lambda$

and $\beta l = G = 2\pi l/\lambda$ radians $= 360 l/\lambda$ degrees (6)

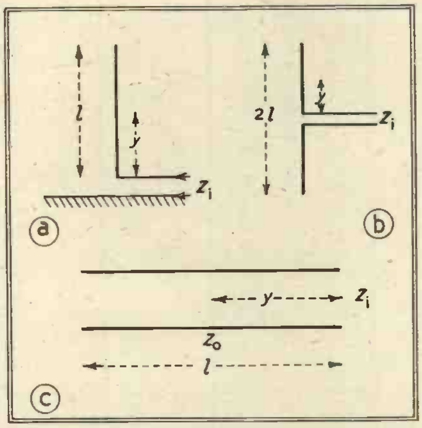


Fig. 1. (a) Grounded vertical aerial of length l. (b) Vertical dipole aerial of total length $2l$. (c) Equivalent circuit represented by an open circuited transmission line of characteristic Impedance Z_0.

represents the electrical length of the line or aerial.*

With normal aerials G_o is very small and for short aerials up to about $G = 60°$ or $l = \lambda/6$ the input reactance of the aerial is large compared with the resistance. Neglecting the resistance term we can simplify equation (1) to

$$X_i = -Z_o \cot G \quad \ldots \quad (7)$$

which is shown plotted in Fig. 2. From this it will be seen that the input reactance of a simple aerial is capacitive up to an aerial length of $l = \lambda 4$ (or $G = 90°$) and then becomes inductive between $l = \lambda/4$ and $l = \lambda/2$ (or between $G = 90°$ and $G = 180°$).

* The use of G for electrical length should not be confused with G_o for conductance, but as G_o is usually neglected, this should not cause the reader any difficulty.

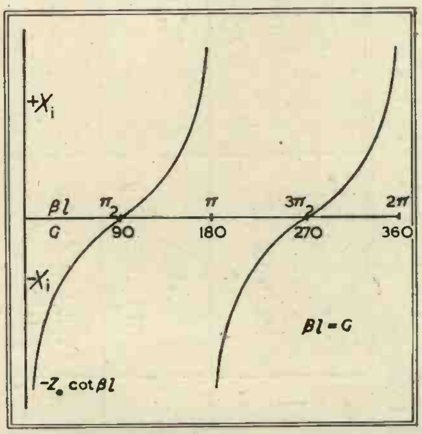


Fig. 2. Input Reactance of open circuit transmission line.

The cycle is then repeated as the aerial length is increased or the operating wavelength reduced with a given aerial length. (*See* also Data Sheets No. 6 to 11).

The transmission line equations employed above are derived on the assumption of uniformly distributed parameters (*i.e.*, L_o, C_o, etc.) with the resulting sinusoidal current distribution.

With the exception of long horizontal wire aerials and conical aerials the distributed parameters vary in magnitude along the length of the aerial. However, the distributed parameters tend to become more and more constant along the length of the aerial as the cross-section becomes reduced. Whatever the shape of the aerial member, if we make the cross sectional dimensions sufficiently small, the distribution of current along its length will tend to be sinusoidal. As $Z_o \approx \sqrt{L_o/C_o}$ we see that with the majority of aerials the characteristic impedance is a varying quantity. If we make the cross-sectional dimensions sufficiently small we can, however, approximate the solution by making use of an Average Characteristic Impedance of the aerial which we will designate by Z_{OA} where

$$Z_{OA} = \frac{1}{l}\int_0^l Z_o(y)\, dy$$

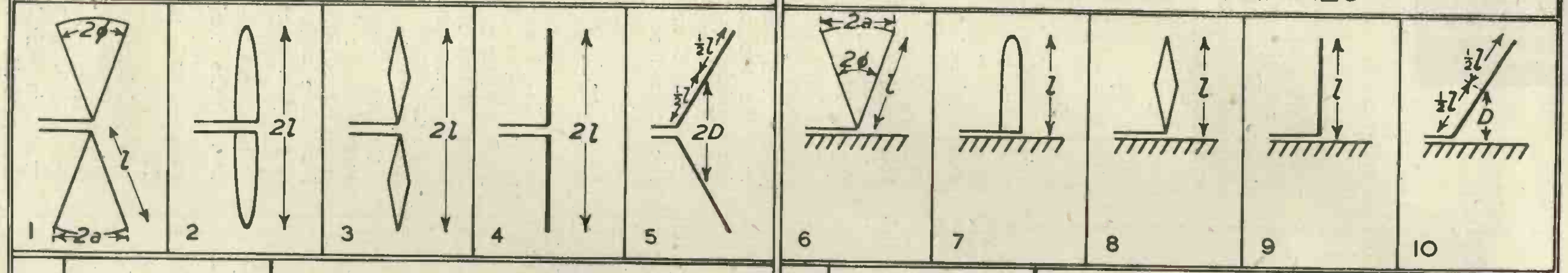
where $Z_o(y)$ is the value of Z_o for an infinitesimally short length of the aerial a distance "y" from the drive point (*see* Fig. 1) and "l" is the total length of a grounded aerial and half the total length of a dipole in free space.

On Data Sheet No. 51 is given the expression for Z_{OA} for a number of aerial forms both of the grounded and free space variety. With the exception of No. 5 and No. 10 the expressions are taken from Schelkunoff; No. 10 from Morrison and Smith. In the case of the conical aerials the distributed parameters are constant and therefore Z_o is constant, that is $Z_{OA} = Z_o$.

It will be seen that the expression for Z_{OA} for a cyindrical grounded aerial is different from that due to Howe ($Z_{OA} = 60 (\log_e l/a - 1)$) usually quoted in text books. The thinner the aerial the more nearly will the two expressions be equal.

DATA SHEET No. 51

FREE SPACE ÆRIALS			GROUNDED ÆRIALS		



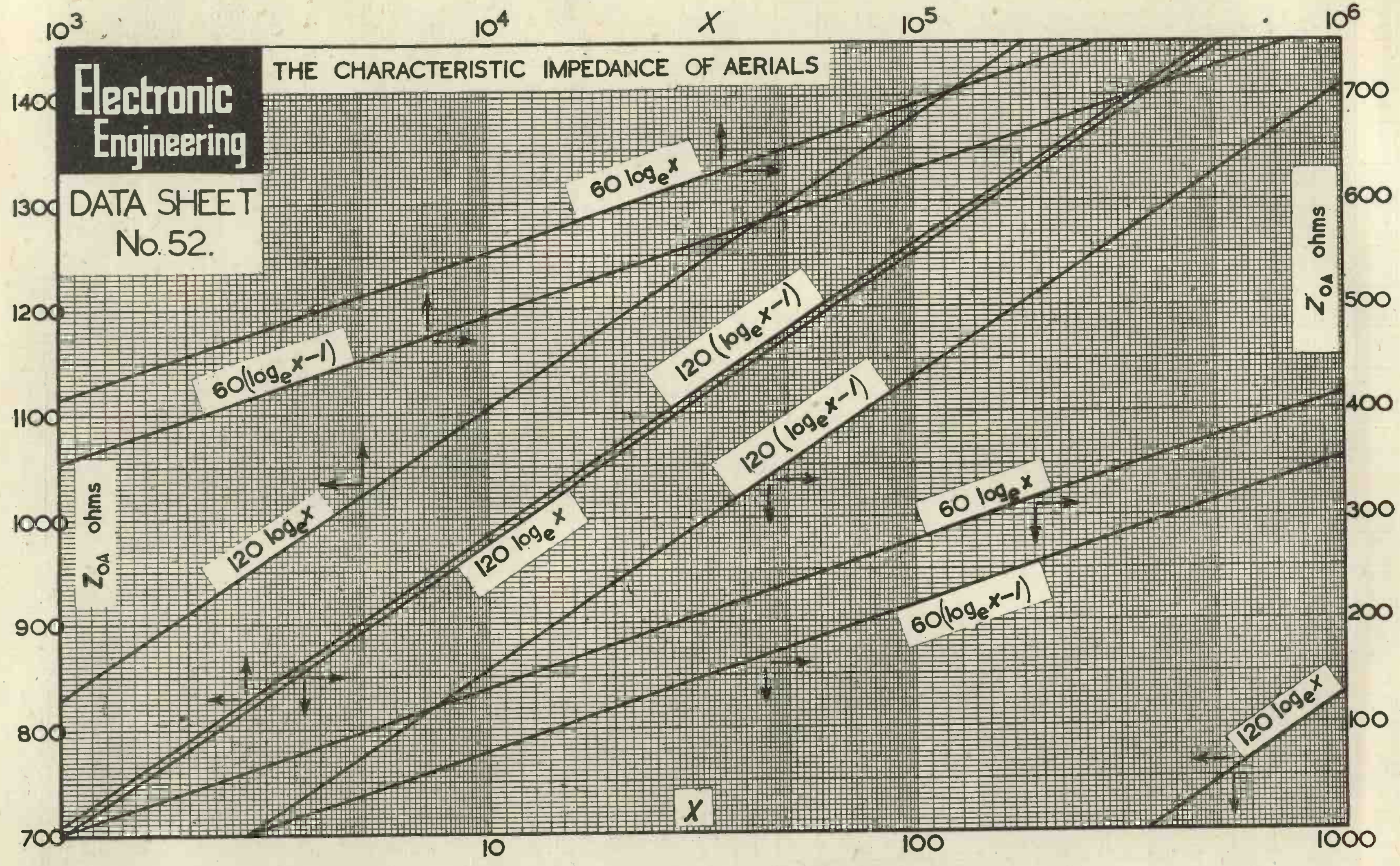
1	BI-CONICAL or HOURGLASS	$Z_0 = 120 \log_e[\cot(\phi/2)]$ ohms When cone angle 2ϕ is small: $Z_0 \approx 120 \log_e[2/\phi] \approx 120 \log_e\left[\frac{2l}{a}\right]$ ohms	6	INVERTED CONICAL	$Z_0 = 60 \log_e[\cot(\phi/2)]$ ohms When cone angle is small: $Z_0 \approx 60 \log_e[2/\phi] \approx 60 \log_e\left[\frac{2l}{a}\right]$ ohms
2	THIN SPHEROIDAL	$Z_{0A} = 120 \log_e\left[\frac{l}{a}\right]$ ohms a = radius at base.	7	THIN SPHEROIDAL	$Z_{0A} = 60 \log_e\left[\frac{l}{a}\right]$ ohms a = radius at base
3	THIN DOUBLE DIAMOND	$Z_{0A} = 120 \log_e\left[\frac{2l}{a}\right]$ ohms a = maximum radius.	8	THIN DIAMOND	$Z_{0A} = 60 \log_e\left[\frac{2l}{a}\right]$ ohms a = maximum radius
4	THIN CYLINDRICAL WIRE	$Z_{0A} = 120\left[\log_e \frac{2l}{a} - 1\right]$ ohms a = radius of wire.	9	CYLINDRICAL WIRE	$Z_{0A} = 60\left[\log_e \frac{2l}{a} - 1\right]$ ohms a = radius of wire.
5	THIN CYLINDRICAL WIRE V-TYPE	$Z_{0A} \approx 120 \log_e\left[\frac{2D}{a}\right]$ ohms $2D$ = average separation; a = radius of wire.	10	INCLINED THIN CYLINDRICAL WIRE	$Z_{0A} \approx 60 \log_e\left[\frac{2D}{a}\right]$ ohms D = average height a = radius of wire

With the exception of Conical Aerials these expressions only apply to aerials with very small cross sectional dimensions

$\log_e x = 2{\cdot}3 \log_{10} x$

In Data Sheet 51 the distance between the two elements of the free space aerials is assumed to be very small and the same assumption is made for the distance between the bottom of the grounded aerial and the ground.

With free space aerials, the aerial is assumed to be a considerable distance (several wavelengths) from the ground so that capacity-to-ground effects are negligible.


Electronic Engineering
DATA SHEET
No. 52.
THE CHARACTERISTIC IMPEDANCE OF AERIALS
X
10^3
10^4
10^5
10^6
Z_{OA} ohms
$60 \log_e x$
$60(\log_e x-1)$
$120 \log_e x$
$120(\log_e x-1)$
1400
1300
1200
1100
1000
900
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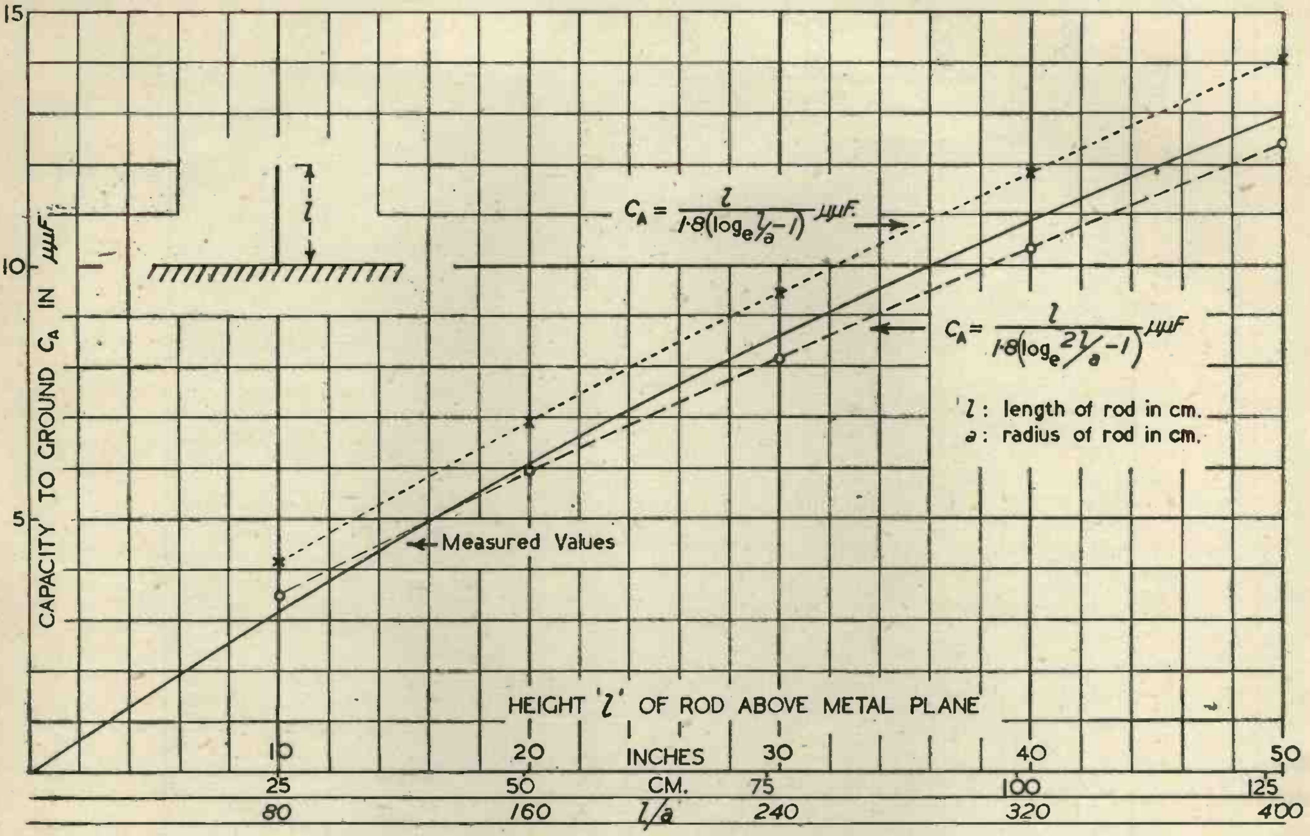
400
300
200
100
10
1000



The measured and calculated capacity to ground of a ⅛" dia. vertical grounded rod mounted on a metal plate 3 ft. by 6 ft.

The measured values were taken at 1.0 Mc./s. by Foster & Mountjoy (*R.C.A. Review* Jan., 1939)

Input Capacity of Short Aerials

From equations (4) and (5) we can write

$$Z_o = \frac{1}{vC_o} \qquad \ldots \quad (8)$$

when $v = c$ we can express the static capacity C_o in $\mu\mu$F by

$$C_o = \frac{33{\cdot}3}{Z_o} \ \mu\mu\text{F. per cm.} \qquad \ldots \quad (9)$$

For aerials whose length does not exceed 60° the input capacity can be calculated from equation (7).

For very short aerials when $Z_o \cot 2\pi l/\lambda \approx Z_o\lambda/2\pi l$ the input capacity C_a of the aerial becomes

$$C_a \approx C_o l \qquad \ldots \quad (10)$$

$$\approx \frac{33{\cdot}3l}{Z_o} \ \mu\mu\text{F.}$$

where C_o and C_a are calculated from Z_{0A} where necessary.

In Fig. 3 are plotted the calculated and measured capacity to ground of an ⅛ in. diameter grounded rod. Two calculated curves are shown one using Schelkunoff's expression (*see* 9 in Data Sheet No. 51) and the other using Prof. Howe's expression. A curve showing the results of measurements carried out by the RCA at 1 Mc/s. where equation (10) is applicable is also shown.

In order to save labour a number of curves have been drawn on Data Sheet No. 52 from which the values of Z_{0A} given in Data Sheet No. 51 can be obtained. It should, however, be remembered that these expressions are for Z_{0A} are only applicable for thin aerials.

Example. The average Characteristic Impedance of a dipole of cylindrical wire ½ cm. in diameter and 5 metres total length ($2l$) at a wavelength of 20 metres is ($2l/a$ = 2,000), Z_{0A} = 792 ohms and the input reactance is therefore

$$X_1 = -792 \cot\left(\frac{360}{8}\right)^{\circ} = -792 \text{ ohms}$$

which is equivalent to a capacity of

$$C_a = \frac{1}{2\pi \times 1.5 \times 10^7 \times 792} \approx 13.4 \ \mu\mu\text{F.}$$

In the above expression the resistive loss has been neglected; but with any aerial the radiation resistance is always present even if the dissipation losses are reduced to zero.

The expression for the attenuation constant where R_o is not neglected, but G_o = O and $R_o/\omega^2L^2 \ll 1$, is:

$$\alpha = R_o/2Z_o$$

If we designate the radiation resistance referred to the current antinode or loop by R_L, it can be shown that when $l = n\lambda/4$ (where n = 1, 3, 5, etc.)

$$R_o \approx 2R_L/l$$

Provided, therefore, that Z_o or Z_{0A} is large (as is the case with thin aerials) the approximation due to neglecting the resistive component is justifiable.

If in Example 1 the diameter of the rod were increased to 4 cm., thus making l/a 125, then $Z_{0A} \approx$ 540 ohms and therefore $X_1 \approx -540$ ohms.

It will be shown in later Data Sheets that the accurate solution for this low value of l/a gives $X_1 \approx -500$ ohms.

Valves and Vehicles

The connection between valves and vehicles is frequently a very direct one — the contact pad in the road surface which controls the operation of traffic lights.

The equipment consists of electron tubes and relays, so arranged that when the contact pad is depressed a current impulse is released into the relay circuit and initiates the light sequence. The apparatus automatically resets itself after a time interval, or after the cessation of further impulses. Sometimes, however, even the mechanical connection is eliminated. Then a " proximity " link is used, consisting of a particular arrangement of valves and circuit design which is sensitive to the proximity of vehicles. In other words, it can " feel " the approach of traffic.

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The Synchronisation of Oscillators

By D. G. TUCKER, B.Sc. (Eng.), A.M.I.E.E. *

Part IV. The Discrimination of a Synchronised Oscillator against Unwanted Signals mixed with the Control Tone

1. Introduction.

Fig. 1 shows a simple feedback oscillator of natural angular frequency ω_o, with a locking tone $E_{syn} \sin \omega_{syn}t$ injected into the grid circuit, and a stray, unwanted signal $E_s \sin \omega_s t$ in series with it. In practice, such a condition arises where the control tone is transmitted from a distance, over a telephone circuit or radio link, for example; circuit noise and cross-talk then represent stray signals. In the particular case of carrier telephony, the control (or "pilot") tone is generally transmitted over a line already carrying a number of communication channels, so that direct or modulated speech signals at levels comparable with that of the control tone are stray signals of importance. The effect of these signals on the synchronisation of carrier telephone circuits may be to produce a "flutter" on any transmitted speech or other signal; this matter will not be pursued in this article, but it is worth pointing out that a synchronised oscillator produces sufficient suppression of the unwanted signal in the carrier generating circuit to ensure that no flutter occurs under ordinary working conditions. Another similar case arises in radio practice, where a modulated carrier tone may be injected into an oscillator in order to extract a fairly pure carrier for automatic tuning purposes.[1]

Here we will investigate only the actual response of the synchronised oscillator itself to an unwanted frequency in the locking circuit. It will be assumed that the output of the oscillator is taken from the anode circuit. Paragraph 5 discusses the effect of taking the output from the terminals of the tuned circuit.

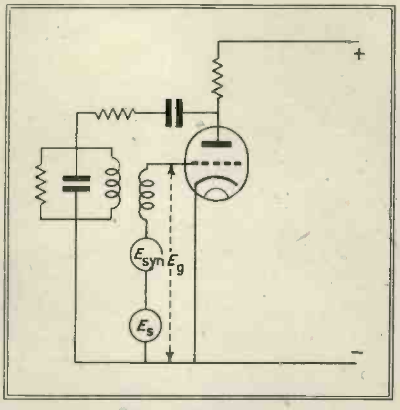

Fig. 1. Oscillator with locking signal *Esyn* and stray signal *Es*.

It will be seen that the oscillator is effectively an amplifier to the injected signals, with tuned positive feedback applied to such an extent that oscillation takes place in the absence of an injected signal. The investigation is made in three sections, according to the frequency of the stray tone relative to the control frequency:—

(a) ω_s is sufficiently different to ω_{syn} to allow the positive feedback at the angular frequency ω_s to be neglected.

(b) ω_s is sufficiently near to ω_{syn} to make the positive feedback important, but is not within the pull-in range of the oscillator.

(c) ω_s lies actually in the pull-in range.

2. The case when the positive feedback at angular frequency ω_s may be neglected.

2.1. The effect of the amplitude of ω_{syn} on the amplification of ω_s

In this case the problem reduces to one of determining the amplification to a signal on the grid, $E_s \sin \omega_s t$, in the presence of the locked oscillation signal $E_{gsyn} \sin \omega_{syn}t$. The amplitude of the latter in the absence of $E_s \sin \omega_s t$ is generally a known quantity, and can in any case be determined approximately as discussed in Part 1. We must know the valve characteristic relating output (anode) voltage to grid voltage; this is generally of the form

$$E_a = \alpha E_g + \beta E_g^2 - \gamma E_g^3 \ldots \text{ etc. } (1)$$

Since $E_g = E_{gsyn} \sin \omega_{syn}t + E_s \sin \omega_s t$, we have, considering only the first three terms,

$$E_a = \alpha[E_{gsyn} \sin \omega_{syn}t + E_s \sin \omega_s t] + \beta[E_{gsyn}^2 \sin^2 \omega_{syn}t + E_s^2 \sin^2 \omega_s t + 2E_{gsyn} E_s \sin \omega_{syn}t . \sin \omega_s t] - \gamma[E_{gsyn}^3 \sin^3 \omega_{syn}t + E_s^3 \sin^3 \omega_s t + 3E_{gsyn}^2 E_s \sin^2 \omega_{syn}t . \sin \omega_s t + 3E_{gsyn} E_s^2 \sin \omega_{syn}t . \sin^2 \omega_s t]$$

Now $\sin^3 \theta = \frac{3}{4} \sin \theta - \frac{1}{4} \sin 3\theta$ and $\sin^2 \theta = \frac{1}{2} - \frac{1}{2} \sin 2\theta$.

Therefore the output of the two fundamental frequencies is given by

$$[\alpha - \tfrac{3}{4} \gamma E_{gsyn}^2 - {}^3/_2 \gamma E_s^2] E_{gsyn} \sin \omega_{syn}l + [\alpha - \tfrac{3}{4} \gamma E_s^2 - {}^3/_2 \gamma E_{gsyn}^2] E_s \sin \omega_s t.$$

In general, $E_s << E_{gsyn}$, and the effect of E_s on the output of ω_{syn} may be neglected. But the second term shows that the effect of E_{gsyn} on the output of ω_s is considerable. We have that the amplification to ω_s is

$$\alpha - \tfrac{3}{4} \gamma E_s^2 - {}^3/_2 \gamma E_{gsyn}^2 \qquad (2a)$$

Almost always we may neglect $\frac{3}{4} E_s^2$ compared with ${}^3/_2 E_{gsyn}^2$; so the amplification to ω_s becomes

$$\alpha - {}^3/_2 \gamma E_{gsyn}^2 \quad \ldots \quad (2b)$$

It is sufficient for most practical purposes to use this simple relation which neglects the terms in equation (1) above the cube term. If, however, relatively large values of E_{gsyn} are involved, appreciably greater accuracy is obtained if the 5th power term is included. It should be noted that the

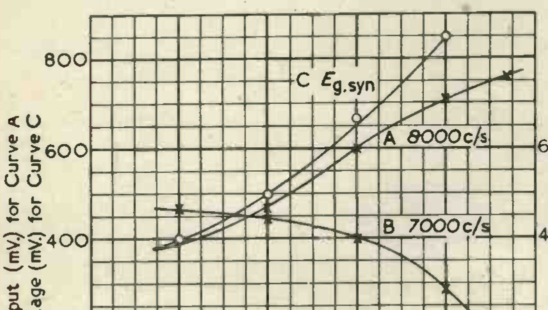

Fig. 2. The effect of *Esyn*. *Es* = 0.1 volt, *fsyn* = 8,000 c/s, *fs* = 7,000 c/s, Q = 10.

* P.O. Research Station.

even powers do not influence the amplification of the fundamental frequency. One objection to taking higher powers is the difficulty of evaluating their coefficients from measured valve characteristics.

2.2 Other non-linear effects—intermodulation products and harmonics.

A full analysis of the general problem of harmonic production and intermodulation in amplifiers has been published by Espley.[2] For present purposes it will be sufficient to state the products obtained assuming that the valve characteristic is sufficiently represented by the cubic equation (1).

Second harmonic terms are

$$\tfrac{1}{2}\beta E_{gsyn}^2 \sin 2\omega_{syn}t + \tfrac{1}{2}\beta E_s^2 \sin 2\omega_s t \quad (3a)$$

Third harmonic terms are

$$\tfrac{1}{4}\gamma E_{gsyn}^3 \sin 3\omega_{syn}t + \tfrac{1}{4}\gamma E_s^3 \sin 3\omega_s t \quad (3b)$$

Second order intermodulation product terms are:

$$\beta E_{gsyn} E_s \cos(\omega_{syn} - \omega_s)t - \beta E_{gsyn} E_s \cos(\omega_{syn} + \omega_s)t \quad (3c)$$

Third order intermodulation product terms are:

$$\tfrac{3}{4}\gamma E_{gsyn}^2 E_s \cos(2\omega_{syn} - \omega_s)t - \tfrac{3}{4}\gamma E_{gsyn}^2 E_s \cos(2\omega_{syn} + \omega_s)t + \tfrac{3}{4}\gamma E_{gsyn} E_s^2 \cos(2\omega_s - \omega_{syn})t - \tfrac{3}{4}\gamma E_{gsyn} E_s^2 \cos(2\omega_s + \omega_{syn})t \quad (3d)$$

The phases relative to the fundamental have been neglected.

2.3. Experimental results.

Fig. 2 shows the results of an experiment on the non-linear effect. The oscillator used in all the experimental work described in this part had a valve type Mazda SP41 and 80 volts H.T. The anode of the oscillator valve was coupled to the grid of an output valve by means of a very high ratio potentiometer, and the voltage applied to the second valve was so small that distortion in it may be neglected. The output millivolts shown in the figures are the output of this buffer valve. In Fig. 2 the direct measurements are shown plotted against E_{syn}, the voltage of injected locking signal, which is, of course, the direct cause of the changes shown. It will be seen how rapidly the output of ω_s falls as E_{syn} is increased.

2.4. Results when ω_{syn} and ω_0 are not the same

The tests described above were carried out with the natural frequency equal to the control frequency. When these are not equal, the output of ω_s is increased owing to the smaller value of E_{gsyn}. Fig. 3 shows the results of a test carried out under the identical conditions of Fig. 2 with $E_{syn} = E_s = 0.1$ volt. The ratio of output of ω_s to output of ω_{syn} is greatly worsened (*i.e.,* increased) as ω_{syn} departs from ω_0.

2.5. The amplification of ω_s is linear when ω_{syn} is constant.

One other important relation is to be noted in this section. Equation (2) shows that if $\frac{3}{4} E_s^2$ is small compared with $^3/_2 E_{gsyn}^2$, as is nearly always the case, then the amplification of ω_s is independent of the value of E_s. That is to say, if E_{syn}, and consequently E_{gsyn}, is maintained constant, then *the amplification of the stray signal is linear.*

3. The case where the positive feedback, at angular frequency ω_s may not be neglected, but ω_s does not lie in the 'pull-in' range.

We have seen in the previous paragraph that the amplification of ω_s without positive feedback is linear owing to the fact that $\frac{3}{4}E_s^2$ is small compared with $^3/_2 E_{gsyn}^2$. In this section we are concerned with values of ω_s for which the positive feedback may not be neglected. We must, therefore introduce a new term E_{gs} to represent the grid amplitude of ω_s as distinct from the injected amplitude E_s. The condition for linear amplification of ω_s now becomes that $\frac{3}{4}E_{gs}^2$ is small compared with $^3/_2 E_{gsyn}^2$. Since, in practice, E_s is never likely to exceed E_{syn} in this range, and will generally be much smaller, we may consider this condition to hold provided ω_s is outside the pull-in range of the oscillator.

The use of a linear amplification law greatly simplifies the analysis. It enables us to neglect the presence of the locking signal provided this is maintained constant, and the positive feedback circuit may be worked out as though ω_s were the only frequency present, although the loop gain at the resonant frequency is unity, since the circuit is evidently capable of free oscillation at this frequency. These conditions are the same as those considered in Appendix 1 of Part 2, and lead correspondingly to the relation

$$\left|\frac{E_{gs}}{E_s}\right| = \sqrt{\frac{1 + Q^2(1 - x_s^2)^2}{(1 - x_s)^2 + Q^2(1 - x_s^2)^2}} \quad (4)$$

This gives the effective gain due to positive feedback at a frequency defined by $x_s = \omega_s/\omega_0$. Apart from this gain, the effects described in paragraph 2 apply equally to the present case.

In Fig. 4 curve (a) gives the gain characteristic calculated from equation (4) for a Q value of 15. Curve (b) shows a measured characteristic of the output voltage of ω_s relative to the output of ω_{syn}, for the same Q value (note that $\omega_0 = \omega_{syn}$ in this test), and it will be seen that the agreement is quite close, considering the difficulty of determining exactly the effective Q of the tuned circuit under its operating conditions. For comparison, the response of the tuned circuit itself is shown in curve (c), considered as a selective circuit in a constant-current path.

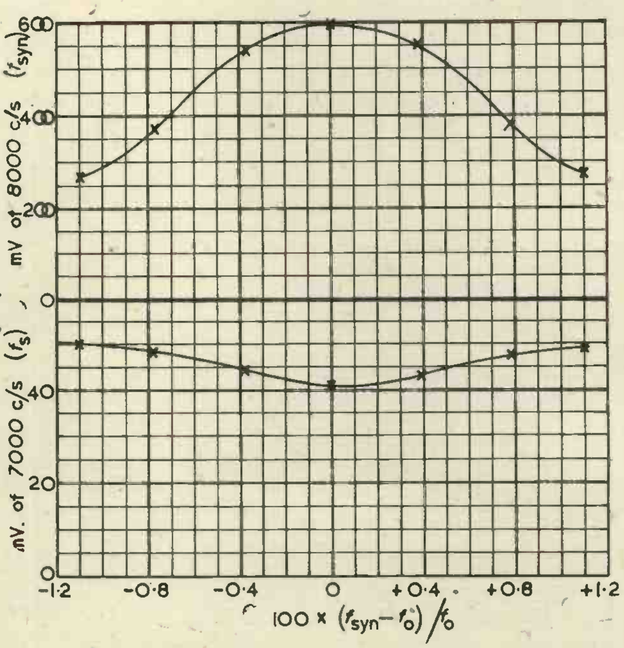

Fig. 3. The effect of ($\omega_0 - \omega_{syn}$). *Esyn = Es = 0.1 volt, fsyn = 8,000 c/s, fs = 7,000 c/s, Q = 10.*

It can be seen from equation (4) that if x_s is very nearly unity, so that $Q^2 (1 - x_s^2)^2 << 1$ and $(1 - x_s)^2 << Q^2 (1 - x_s^2)^2$, then at a given value of x_s,

$$\text{gain due to feedback} \propto 1/Q \quad (5)$$

4. The case where ω_s lies actually in the 'pull-in' range.

4.1. Analysis.

In this case ω_s is so close to ω_{syn} that the amplification of each is dependent

on the amplitude of the other, and, consequently, no simplifications are justifiable. The analysis becomes very involved, and is not likely to be very useful in practice; therefore only an indication of how it can be effected is given here.

From paragraph 2.1 we have that the amplification of ω_s is $\alpha - \frac{3}{4}\gamma E_{gs}^2 - {}^3/_2\,\gamma E_{gsyn}^2$ and that the amplification of ω_{syn} is $\alpha - \frac{3}{4}\gamma\, E_{gsyn}^2 - {}^3/_2\,\gamma\, E_{gs}^2$. (The term E_{gs} has been substituted for E_s as described in paragraph 3).

It is convenient to consider the coefficients α and γ as representing the loop gain characteristic, *i.e.*, from grid back to the output of the grid coil. Thus we obtain the relationships:

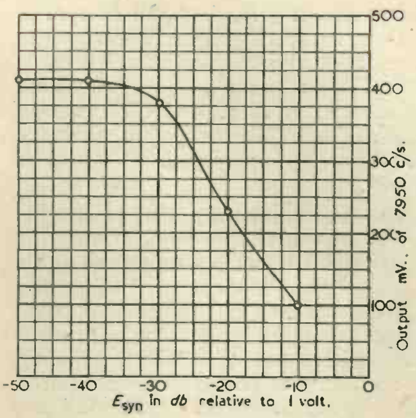

Fig. 5. The effect of varying *Esyn* when *fo* = *fsyn* = 8,000 c/s and *fs* = 7,950 c/s, *Es* = 0.1 volt, Q = 10.

$$E_{gs} = E_s + (a + jb)\,[\alpha - \tfrac{3}{4}\gamma\,|E_{gs}|^2 - {}^3/_2\,\gamma\,|E_{gsyn}|^2]\,E_{gs} \quad \ldots \quad \ldots \quad (6a)$$

and

$$E_{gsyn} = E_{syn} + (A + jB)\,[\alpha - \tfrac{3}{4}\gamma\,|E_{gsyn}|^2 - {}^3/_2\,\gamma\,|E_{gs}|^2]\,E_{gsyn} \quad \ldots \quad (6b)$$

where $a + jb = x_s.\ \dfrac{1 + jQ(1 - x_s^2)}{1 + Q^2(1 - x_s^2)^2}$

and $A + jB = x_{syn}\ \dfrac{1 + jQ(1 - x_{syn}^2)}{1 + Q^2(1 - x_{syn}^2)^2}$

where $x_s = \omega_s/\omega_o$ and $x_{syn} = \omega_{syn}/\omega_o$ (not necessarily unity).

Also, E_{gs} is complex; assume that

$$E_{gs} = e_{s1} + je_{s2}$$

Similarly $E_{gsyn} = e_{syn1} + je_{syn2}$

If these expressions are substituted in equations (6a) and (6b), and in each equation the real and imaginary terms are made into separate equations, then we evidently obtain four simultaneous cubic equations with the four variables

e_{s1}, e_{s2}, e_{syn1}, and e_{syn2}.

and if all the other terms are known, these equations can theoretically be solved for these voltages. The moduli $|E_{gs}|$ and $|E_{gsyn}|$ can then be obtained, and also the phase angles, if required. In practice, the solution is a matter of some complexity.

4.2. Experimental results.

Some experiments were made to demonstrate the behaviour of the oscillator under these conditions. The results afford ample evidence of the physical nature of synchronisation, *i.e.*, that when a locking signal within a suitable frequency range is applied, the free oscillation is suppressed due to the non-linear amplification of the circuit (see Appendix 1 of Part 2). If two locking signals are applied (which is the case we are considering here, since ω_s and ω_{syn} both lie within the locking range), then these both produce forced oscillations at amplitudes depending on one another and on the relation of their frequencies to the resonant frequency of the oscillator tuned circuit.

In Fig. 5 is shown the variation in the output of a tone of frequency 7,950 c/s as the input level of a tone of frequency 8,000 c/s is varied. The natural frequency of the oscillator was 8,000 c/s, and the input voltage of 7,950 c/s was 0.1 volt. The Q of the tuned circuit was 10. This low value was used in order that the locking range might be relatively large, and at the normal locking voltage of 0.1 volt might allow the use of testing frequencies sufficiently different to be measured separately on a wave analyser, without error or undue difficulty. When E_{syn} was 0.1 volt (*i.e.*, − 20 db on the scale) the output of ω_{syn} was 520 mV. It will be seen that as E_{syn} is reduced, the output of ω_s increases, and by the time E_{syn} is only about 0.01 volt, the output of ω_s has reached its maximum value, and is now independent of E_{syn}. In spite of the fact that $\omega_{syn} = \omega_o$, we see that ω_s is now effectively the synchronising tone, and ω_{syn} behaves as a stray signal.

Fig. 6 shows the variation in output of the 7,950 c/s and 8,000 c/s tones as the natural frequency of the oscillator is varied. E_{syn} and E_s were both maintained constant at 0.1 volt. When the natural frequency is roughly half-

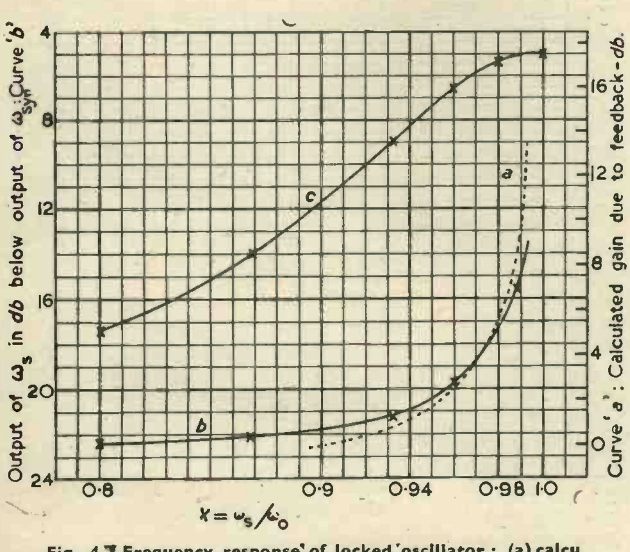

Fig. 4. Frequency response of locked oscillator; (a) calculated, (b) measured, (c) response of tuned circuit alone. Q = 15, *Eg.syn* = 0.7 volt, *Esyn* = *Es* = 0.1 volt.

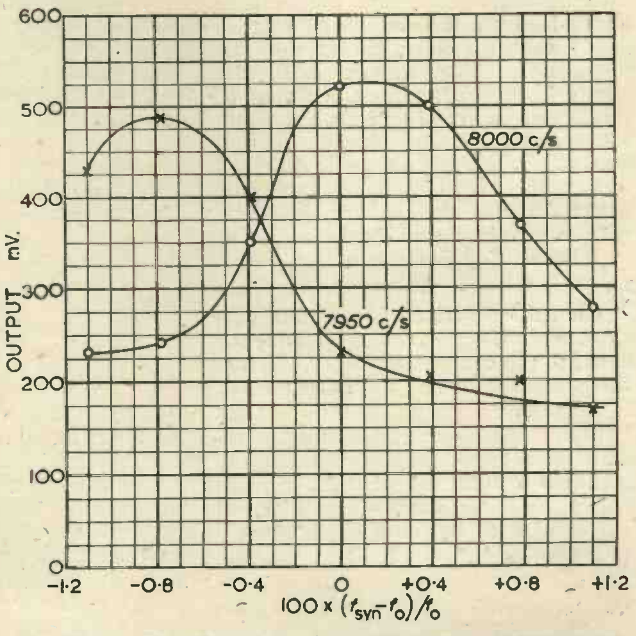

Fig. 6. The effect of ($\omega_o - \omega_{syn}$) when *fsyn* = 8,000 c/s and *fs* = 7,950 c/s, *Esyn* = *Es* = 0.1 volt, Q = 10.

way between 7,950 c/s and 8,000 c/s, the outputs of the two frequencies are equal.

It will be seen that the idea of selectivity of the synchronised oscillator, suggested by the work of paragraph 3 and Fig. 4, can hardly be applied in practice to the case where ω_s lies within the locking range, since variations of natural frequency (which are bound to occur in practice) override all other considerations.

5. The effect of taking the output from the tuned circuit terminals instead of from the anode circuit.

In Fig. 4, the frequency response of the oscillator was shown in terms of the amplification of an unwanted signal injected into the grid circuit. The response of the oscillator tuned circuit was also shown for comparison. From these curves it will be quite evident that the effect of taking the output from the terminals of the tuned circuit will not greatly modify the frequency response of the oscillator in that region where the positive feedback is effective. Over the rest of the frequency band, the response will be that of the tuned circuit, instead of being flat. The effect of the valve non-linearity is unchanged.

It will be seen that it is advantageous in practice to take the output from the tuned circuit in those cases where interference from frequencies remote from ω_{syn} is to be expected. This is a less common problem, however; it is generally those frequencies near ω_{syn} which are found troublesome in practice.

6. Sideband pull-in.

An interesting effect that is of some importance in radio work is known as "sideband pull-in." If a tone of angular frequency $\omega_{syn} \pm \omega_s$ is injected into an oscillator of natural angular frequency ω_0 which is modulated by an angular frequency ω_s, then the oscillator can be synchronised to the angular frequency ω_{syn} if $(\omega_{syn} - \omega_0)$ is sufficiently small. The mechanism of this "sideband pull-in" is clearly similar to ordinary direct synchronisation, and depends on the intermodulation terms (*i.e.*, the even power terms) in the valve equation (1). A graphical treatment (without experimental evidence) has been published by Bab.[3]

7. Conclusions.

The work described in this part has shown that the analysis of the problem of unwanted signals mixed with the control tone can be dealt with quite simply by considering two factors:—(a) valve non-linearity and (b) the increasing positive feedback as the unwanted frequency approaches the wanted frequency. These two factors may be considered quite independently over the whole frequency range except for that very small part lying more or less in the locking frequency range.

The main conclusions affecting the practical design of synchronising systems are:—

(a) If the level of locking tone alone is increased, the voltage ratio of wanted to unwanted frequency in the output is increased.

(b) If the input levels of locking and stray frequencies are both raised by the same amount, the above ratio may be increased or decreased according to circumstances.

(c) Other things remaining constant, the output of unwanted frequency if taken from the anode of the oscillator valve, is constant over most of the frequency range, but over a small range (the extent of which is greater for lower Q values in the oscillator tuned circuit) the positive feedback becomes effective, and an increased output is obtained depending on the smallness of the difference between wanted and unwanted frequencies.

(d) Within the locking frequency range the influence of the unwanted and wanted locking frequencies is of the same order relative to their input levels, and, because of drifting of the natural frequency in practice, the ratio of the two outputs is variable and not easily computed.

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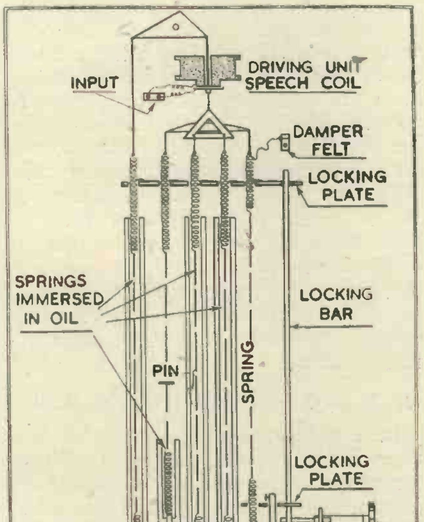
Synthetic Reverberation

By D. W. ALDOUS

MANY methods have been developed for adding synthetic reverberation, which can be defined as a means of artificially producing any desired rate of sound decay, to recording material. Until very recently reverberation chambers and reverberation pipes, staggered or offset tracks, and endless steel or film tapes with a number of time-displaced reproducing heads, have been used for this purpose with considerable success.

Now a device known as a "Reverberstat" has been made available, designed for this purpose. Mr. J. K. Hilliard, of M.G.M. Studios in America, recently gave members of the Society of Motion Picture Engineers some details of this new instrument.

It consists essentially of a permanent magnet loudspeaker actuating a rocker-arm to which springs are attached, and these set into vibration a piezo-electric crystal. The springs are surrounded by tubes of oil that provide the necessary damping. The vibrations of the crystal produce an electric current, which is then amplified and combined with the original signal. The time of reverberation is controlled by the length of the springs and the oil damping around the springs. The device is constructed as a compact unit, with dimensions approximately 4 ft. long, 6 in. wide, and 3 in. deep. A cross-section of this unit is shown in the accompanying figure.



It is apparent that it does not occupy much space as compared with the conventional acoustic chambers necessary for most of the other methods, and it is not susceptible to external noises to the same degree. As many as three such units are used at one recording session to create the desired reverberation in dialogue and music tracks, using different equalisers, depending upon the type of reverberation required.

Television After the War

A continuation of the discussion which took place at a meeting of the Wireless Section of the I.E.E. part of which was given in the July issue.

Mr. T. E. Goldup (Mullard W. S. Co.).

In considering the particular aspect of the television problem raised by Mr. Edwards in his opening remarks, we must at the same time take into consideration many other relevant factors, such as the improvements in the cathode-ray tube, especially as regards spot size and screen colour, the circuit design as a whole, and last but not least the economics of the manufacturing problem.

During the war we have been able to enlarge our experience and knowledge with regard to the use of very high frequencies, and when the time comes for a television system to be installed at carrier frequencies of the value suggested by Mr. Edwards, we shall find that the valves and the components will be available, together with accumulated practical experience in their use.

If we are to progress in post-war television on the lines indicated by Mr. Edwards, there will have to be close liaison between the circuit engineer and the valve engineer. Too often there has been evidence of lack of this liaison which we valve people have so much desired. We find often that we design experimental valves to go into circuits, and when these circuits are put into production receivers they develop a number of defects which then have to be cleared up. These would not be present if the valve engineer had been working with the circuit engineer from the outset.

In his opening remarks, Mr. Edwards refers chiefly to television as an entertainment, but we must also consider in the post-war period some of the possible commercial applications of television. Those of us who are thinking about this problem can name quite a number of successful applications for television in industry, and we agree that a vast field of work and research lies before us.

I personally would like to see a more intensive interest by the Wireless Section of the I.E.E. in the subject of television generally, together with more informal meetings of this character dealing with other aspects of television.

Mr. D. A. Bell (A. C. Cossor) :

In considering the band-width required for colour television, it should be remembered that in monochromatic television the minimum frame frequency was fixed on grounds of flicker rather than reproduction of rapidly moving objects. The eye is more sensitive to absolute changes of intensity than to changes of colour, a fact which is utilised in the flicker photometer, so that it may not be necessary to increase the total number of frames in the same ratio as the number of colours transmitted. There is, however, no doubt that a substantial increase in band-width is essential for adequate colour television and would therefore necessitate an increase in the carrier frequency above the values in use.

Mr. J. Rhys-Jones (Plessey Co.)

I regret to note that the previous speakers show a lack of a commercial mindedness which would have been so evident at a meeting of this type held before the war.

I would suggest that the problem industry will have to face, is to supply the public with a service which is to be as good as possible at a price which is as low as possible.

The solution of this problem is purely one of economics, and the economic requirements can be considered under two headings, namely, customer economics and supply economics. The more important group is, of course, that referring to the customer.

It is possible that cheaper receivers can be supplied by not fitting facilities which a high definition transmission makes possible, *e.g.*, a high definition receiver requires a large number of low gain stages of amplification owing to the large band-width coverage required. The time bases may become slightly involved owing to the large number of lines used together with inter-lacing features, etc. A cheap receiver could, however, be built using higher gain, smaller band-width amplifying stages, thus effecting economy in the receiver and perhaps still further effecting economy by not attempting to achieve an inter-laced picture.

Dr. R. C. G. Williams (Murphy Radio)

In considering this matter of the best choice of transmission constants for post-war television, we should be careful not to lose sight of the associated economic problem and it might be useful to review briefly the history of television receiver prices up to the outbreak of war.

When the Alexandra Palace service first started, the various television manufacturers marketed only a small number of hand-made sets, selling at round about £60 each. This was followed by an interim period of semi-tooling for about two years before the war when what was perhaps the most popular model, the console type cabinet with a 9 in. cathode-ray tube, was being sold in fair quantities by a number of manufacturers at about £30. Over both the initial development period and this interim period little tooling was carried out and the selling prices were effectively subsidised in order to bring them within reach of the public. The stage we had reached immediately before the outbreak of war was that nearly all the radio manufacturers had tooled and were ready to go into, what was for television, large scale production on a "bread and butter" television specification selling at about £30. I think all companies were hoping that with the tooling and the larger quantities, these prices would make teevision manufacture self-supporting. The future then appeared to lie in an extension to the television service which would increase the viewing public and a progressive improvement in manufacturing efficiency of sets, valves, and components, to get the price of this "bread and butter" model as low as possible. It was generally the experience of the industry that the bigger sales of radio sets were in the £10 to £12 category and we had yet to find the corresponding optimum price/specification compromise for television.

At this stage the war intervened and further work has been at a standstill. As I see it, wartime developments lead to the possibility of three lines of action :—

(a) Leaving the transmission standards as they were pre-war and making use of all the manufacturing improvements which have resulted from the war, particularly in the greater use of plastics and die castings to produce sets more efficiently and sell them to the public at a lower price. This, combined with an extension to the television transmission services, would probably result in the most rapid immediate extension of the industry.

(b) To make use of the improved radio technique which has been developed during the war to reconsider our transmission and

reception standards and possibly lay the foundations of a service with improved picture quality in the years to come. The proposals made in Mr. Edward's opening remarks are directed at one important aspect of this line of action.

(c) The possible political consequences of the war which should result, and I think we all hope *will* result, in a greater degree of international co-operation and the possibilities of using the same picture standards, at any rate over much of the continent of Europe.

I must apologise for broadening the discussion well outside the scope of the title of the meeting, but I do think it is important to bear these matters in mind as a background to the very interesting discussion which is taking place. My own view is that the change to 525 lines would provide a degree of picture improvement hardly sufficient to justify compromising the advantages of bending all our efforts to economical and rapid production unless it were associated with international standardisation, but this must, of course, remain as a purely personal opinion.

In conclusion, I would like to say that my own view, which I believe is shared by a very great number of pre-war viewers, is that the picture standard was of high entertainment value, and that I would want to consider very carefully the associated added cost to weigh against the advantages of any suggested improvement. In short—we might do a great deal worse than revert to our pre-war standards.

Mr. E. E. Shelton (Mullard)

Whatever the system and definition decided upon, the cathode-ray tube in the receiver has to be capable of reproducing the picture satisfactorily.

The cathode-ray tube designer is therefore called upon to produce a spot which will resolve the lines of the raster. If, then, the circuit engineer designs his circuits so that a chequer board black and white pattern of squares, with sides equal to the width of a line, is reproduced by only a sinusoidal variation of brightness (*i.e.,* the usual method of calculating the required frequency band), he is not doing his part towards giving the viewer a picture with the resolution of which the system is capable. The difference in resolution of detail in the vertical and horizontal directions was readily observable in certain commercial television receivers before the war, but the effect was much reduced or absent in the "monitor" pictures at Alexandra Palace. This difference is to be expected, for any failure in the receiver to provide response over the required frequency band reduces only the definition *along* the lines, the vertical resolution is assured since the lines are bound to be discrete. If the early contributions to this discussion mean that the circuit engineer now finds himself able to provide an increased frequency band at the old gain per stage, I suggest that the first step should be, not to increase the number of lines in the picture, but to make full use of the possible definition by increasing the resolution along the lines.

Mr. O. J. Russell (*communicated*)

In my view the whole question of television has been overshadowed by an unconscious comparison with the cinema. This is very clearly indicated by the fact that the choice of screen shape has been dictated by the format of the cinema screen. Moreover, this obsession with the cinema is clearly indicated by the whole history of articles and discussions upon television from the aspect of home entertainment. Upon the beginning of the Alexandra Palace television service, the comparisons of images was constantly referred to the cinema.

The position of television appears to be exactly analogous to the early days of the cinema, when comparison with the legitimate stage peppered every article upon the future of the cinema. The cinema, however, has by now largely outgrown this early inferiority complex, and it is clear from the writing of critics that the function and technique of the cinema is by virtue of its technics inherently different, although allied to, the stage. It is time, therefore, for the realisation that television is not merely a cinema show produced by a rather more clever technical process. The public are not interested in technical miracles, they judge the product finally upon a purely entertainment basis.

If television is to have a value and art of its own, rather than to be merely a novel and inefficient form of cinematograph, the balance of technical and aesthetic and psychological factors may have to be drastically altered. Purely upon a technical basis the cinema is streets ahead of anything that television can do when *imitating* the cinema. Television, if it is to become a vehicle for a new art form, must appreciate its limitations and capitalise upon its advantages.

The writer is in favour of boldly abandoning the present picture format, which in itself is a miserable legacy from the cinema. From the point of view of presenting programme material of an intimate nature, and hence operating largely in closeup or semi-closeup poses, the present picture ratio is wasteful. For the transmission of the proposed material we could use a picture aspect ratio in which the picture height is greater than the width in the ratio of 3 : 2. A little experiment will prove that almost any head and shoulders portrait can be comfortably framed in this picture ratio. Moreover, from the point of view of aesthetic satisfaction, which text-books on photography take so much space in expounding, such a frame provides a neat and unobtrusive surrounding for a face.

Practically all portraits are framed in a ratio approximating to this projected 2 : 3 ratio, and the general effect is one of general satisfaction. No use of ratios analogous to the present cinema shaped screen for portrait work occurs to me, and, in fact, such a use would in general be inartistic and inadmissible. Technically, the use of such a ratio is even more important, for a little calculation will show that if we are interested in increasing detail, the number of lines can be increased by about 40 per cent. without increasing the bandwidth, giving a worthwhile increase in definition, while in cases where the face and expression of the speaker are of major importance the face could be made to fit the picture aperture extremely closely, with a consequent further slight improvement in overall definition. Even if we decide to radiate a full colour picture we can do so on a four-hundred line basis without a materially increased bandwidth. In fact, for the same bandwidth as occupied by the Alexandra Palace station, a full colour picture may be radiated using the 2 : 3 ratio picture with a definition of approximately 390 lines.

However, it might well be objected that the subject matter radiated by the television station of the future should not be tied down to a 2 : 3 ratio frame, although this can be utilised for scenes involving more than one performer. The writer is firmly of the opinion that the present 5 : 4 ratio should be scrapped. Thus a good case might be made out for a square picture ratio, especially as this enables the most efficient use to be made of the round end of a cathode-ray tube. The increase in definition thus obtained works out at about 12 per cent. for the same band width. This picture ratio also reflects the trend of modern camera design, where the $2\frac{1}{4}$ inch square negative represents a very effect compromise of many factors, and efficiently utilises the cir-

Some time ago we were approached in connection with a steam pipe which was continually being fractured as a result of vibrations excited by the flow of the steam. Simple precautions had not afforded a satisfactory solution and we were asked whether we could throw further light on the problem.

We supplied a portable Vibration Analyser which resolved the vibration into its component parts and disclosed an unsuspected mode of vibration. An examination of the structure of the pipe and its housings quickly showed where this vibration could arise, and steps were taken to damp out this particular mode, with the result that the trouble was cured.

This is just another example of the way in which electronic technique can be brought to the aid of industry. If you have a problem let us see what we can do. All we ask is your patience if we take longer than we should like, owing to the heavy demands on our facilities just at present.

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Bandwidth and Definition for Various Frame Ratios

Video Band	Plain	Stereo	Full Colour	Stereo/Full Colour	Format
7.6 Mc/s.	1100	780	760	520	2 : 3
	1000	710	690	480	4 : 5
	896	640	620	430	SQUARE
	800	570	550	380	5 : 4
3.2 Mc/s.	714	500	490	340	2 : 3
	656	470	450	310	4 : 5
	590	420	410	280	SQUARE
	525	370	360	250	5 : 4
2.5 Mc/s.	632	450	440	300	2 : 3
	592	420	410	280	4 : 5
	520	370	360	250	SQUARE
	465	330	320	220	5 : 4
1.9 Mc/s.	551	390	380	260	2 : 3
	490	350	340	230	4 : 5
	453	320	310	220	SQUARE
	405	290	280	190	5 : 4

Note : Owing to uncertainty as to the exact factor, values for colour and stereo pictures are calculated to the nearest ten lines).

cular field of view of the camera lens. However, bearing in view the personal and intimate aspect of television entertainment, a ratio that has much to commend it both for ability to cover a large variety of subjects and effective use of bandwidth might be a compromise between the square picture and the 2 : 3 format. The fact that by using a new picture shape, the use of colour becomes in the realm of practical application without loss of detail is also a point that should be considered. To present these facts, the table given above shows the number of lines required for black and white pictures, stereo-pictures, full colour pictures, and stereo-colour pictures. The figures for colour images are based on a factor derived from the fact that the frame frequency need not be so great as expected, owing to the rarity of purely monochromatic subject matter. Stereo figures are based upon the transmission of two complete images for the normal frame frequency. The advantage of colour over a plain black and white picture would appear on these figures to outweigh any considerations of stereo images, and the introduction of colour may well prove to be one of the factors that will really popularise television as a public entertainment.

Man-made Earthquakes

(From *The Daily Telegraph*)

MR. PURBRICK, the white-haired bespectacled M.P. for Walton, pursues with benign persistence his design of discomfiting the enemy by induction of earthquakes. He has already given the House of Commons a laugh by suggesting that this might be accomplished by dropping a bomb down the crater of Vesuvius.

Yesterday he gave it another by asking the Government to investigate

> "the application in America whereby a neutraliser man-made electrical disturbance more powerful than the greatest storms of thunder and lightning can be reduced to a whisper," and to "consider the applicability of this method for the artificial promotion of seismic disturbances, volcanic eruptions, &c."

Mr. A. S. L. Young, a Government Whip, solemnly replied that further information was being sought, though the Government were advised that the device was unlikely to be of use as a generator of seismic or volcanic disturbances.

The following exchange then ensued:

> Mr. Austin Hopkinson: "Can the Hon. Gentleman explain the exact meaning of the phrase 'neutraliser man-made electric disturbance'?"
> Mr. Young (apologetically): "I am afraid that is beyond me."

Don't worry, Mr. Young, its beyond us, too.

Frequency Modulation in Record Reproduction

The following account of the use of a frequency modulation system for reproducing gramophone records is taken from the paper by G. L. Beers and C. M. Sinnett in the *Journal of the Society of Motion Picture Engineers* (April 1943). The original paper contains a detailed analysis of the various factors in design of reproducers which has had to be omitted in this abstract.

THE remarkable increase in the sale of phonograph records during the past few years is a definite indication of the returning public interest in records as a medium of home entertainment. If the present interest in phonograph records is to be maintained, on a permanent basis, it is essential that the reproduction of sound from records be at least comparable to or preferably better than that which be obtained from radio broadcasting.

During the past few years, an investigation was conducted to determine the prospects of materially improving the overall performance of record-reproducing systems. One phase of the investigation was directed toward the possibility of reproducing frequencies up to 10,000 or 12,000 cycles from standard shellac records without the introduction of objectionable surface noise. In the course of this investigation, the possibilities of producing a frequency-modulated signal by means of a special pick-up and associated circuits was investigated. Fig. 1 shows in outline form the general construction of an experimental frequency modulation pick-up. A metal frame or mounting block is provided as a support for an insulated plate which is the high-potential side of the pick-up. To this mounting block is also attached a thin metal ribbon. The ribbon, which is mounted in a plane parallel to the insulated plate and spaced from it by a small air-gap, is placed under tension in order to increase the natural resonance frequency of the system. The stylus-supporting wire is anchored to the mounting block at its upper end. It is attached to the ribbon at approximately the mid-point of its length and its free end is bent in a plane essentially parallel to the record groove. The sapphire which is used as a stylus is attached to the end of the wire. The portion of the wire between the ribbon and the sapphire provides sufficient vertical compliance to minimise mechanical noise and to reduce distortion due to pinch-effect. From the figure it is apparent that displacement of the stylus laterally results in a change in the position of the ribbon with respect to the fixed plate and thus produces a change in capacity. The overall length of the mounting block shown in Fig. 1 is approximately one-half inch. The normal spacing between the fixed plate and the ribbon is approximately 0.004 inch.

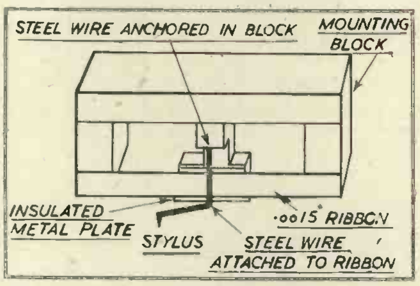


Fig. 1. Experimental frequency modulation pick-up.

From a purely theoretical standpoint it is essential that in a frequency modulation pick-up the change in capacity with displacement of the stylus be such as to produce a linear relationship between frequency change and motion of the stylus. In other words, the variable capacitor formed by the elements of the pick-up should, in radio terminology, be of the straight-line frequency type. From a practical standpoint the distortion introduced by a pick-up constructed along the lines indicated in Fig. 1, when used with circuits to be described later, is sufficiently low as to to be substantially negligible.

Circuit Considerations

The essential circuit considerations which are involved in the design of a frequency-modulation record reproducing system may be stated as follows:

(1) The carrier frequency to be employed.
(2) A suitable oscillator circuit for use with the pick-up.
(3) The type of frequency discriminator-rectifier combination to employ.

A study of the question of the operating frequency to use in a frequency modulation phonograph system leads to the conclusion that carrier frequencies as low as those used in the intermediate-frequency amplifiers of radio receivers and as high as those employed for frequency modulation broadcasting will give satisfactory results. If the phonograph is to be used in combination with a radio receiver there may be some advantage in using a carrier frequency which

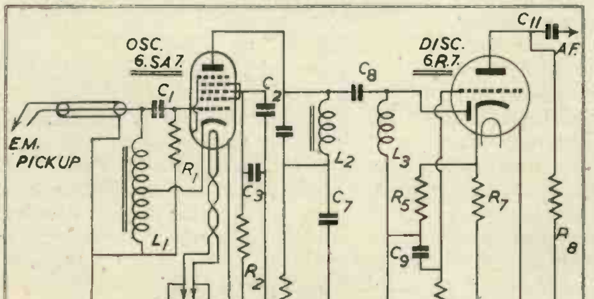


Fig. 2. Oscillator and Frequency-discriminator-rectifier circuit.

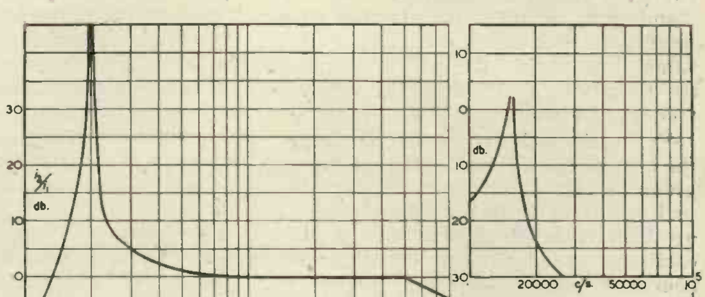
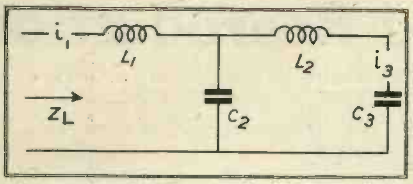
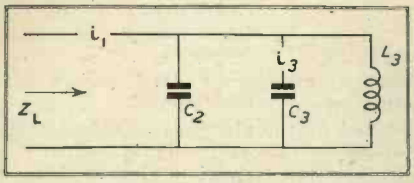


Fig. 5. Calculated response characteristic of pick-up and arm.





Figs. 3 and 4 (left). Equivalent circuits for high and low frequencies.

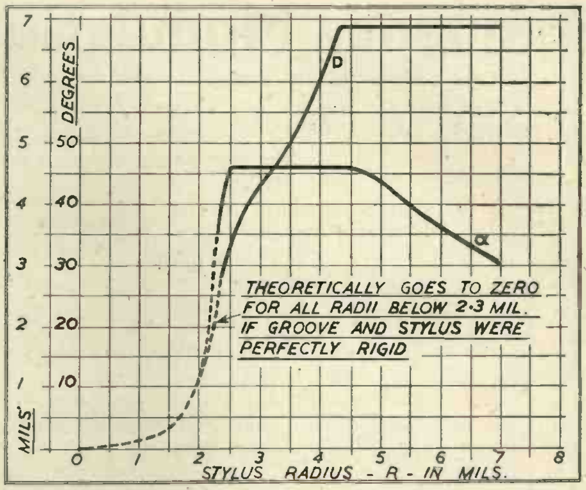


Fig. 7 (right). Variation of d and α with stylus radius.

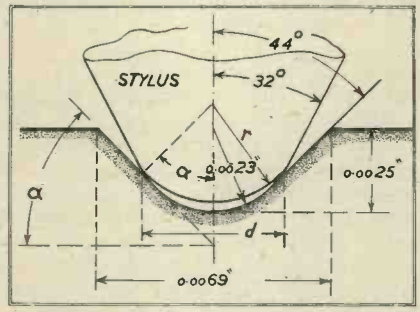


Fig. 6 (below). Stylus seated in record groove.

permits the use of one or more of the intermediate-frequency amplifier circuits as a frequency-discriminating network for converting the frequency-modulated signal into amplitude modulation prior to detection. However, if the phonograph is designed as a separate device it may be desirable to use a frequency in the neighbourhood of 30 megacycles, particularly in case some frequency in this region is assigned by the F.C.C. for diathermy machines. If a carrier frequency is used in a band thus allocated by the F.C.C. no special shielding would be required to prevent interference with other radio services. The signal level provided at the discriminator by the frequency modulated oscillator can readily be made quite high, so there is no likelihood of diathermy machines or other electrical equipment causing interference with the phonograph.

Since the oscillator and frequency discriminator-rectifier circuits are to a considerable extent interdependent, they will be discussed together. Fig. 2 is a schematic diagram of circuits which have given very satisfactory results. The circuit problem in connexion with the oscillator is to provide an arrangement which will have sufficient frequency stability from the standpoint of line-voltage variations, temperature changes, etc., and at the same time enable the pick-up capacity variations to produce the desired frequency change.

From the standpoint of obtaining the maximum frequency change for a given variation in capacity at the pick-up, it is desirable that the pick-up be connected directly across the oscillator tuned circuit. This can, of course, be accomplished by mounting the oscillator tube and associated circuit elements at the pick-up end of the tone arm.

This arrangement has not been found to be particularly desirable because the tone arm is made unduly large and the heat from the oscillator tube causes the end of the tone arm, which is handled by the user, to become uncomfortably hot. The same result, however, can be accomplished by mounting the oscillator tube on the main instrument chassis and connecting it to the pick-up through a resonant transmission line, which is used as the oscillator tuned circuit. It has been found that by connecting the pick-up previously described through a relatively low-capacity line to a conventional oscillator circuit as shown in the diagram a sufficient frequency shift is obtained to give the desired audio-frequency output. In this case the transmission line is treated as a lumped capacity. The line is included as an integral part of the tone arm.

It will be noted that the oscillator tube employed is of the 6SA7 type. This tube permits the use of electronic coupling between the oscillator and discriminator circuits. The oscillator frequency is adjustable by means of an iron core which is associated with the inductance L_1 shown in the diagram.

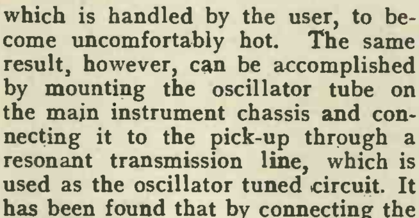


Fig. 8. Tracking loss at 7,000 c/s. for various radii of stylus.

A simple resonant circuit is utilised as the means for converting the oscillator frequency variations into changes in the amplitude of the signal applied to the diode portion of the 6R7 tube. A powdered-iron core associated with inductance L_2 is used to tune this circuit so that the mean oscillator frequency falls at approximately the 70 per cent. response point on one side of the selectivity characteristic. The rectification of the r-f signal by the diode develops an audio-frequency potential across the resistor R_6. This audio-frequency potential is then amplified by the triode section of the 6R7. The output voltage which appears across resistor R_8 in the plate circuit of the 6R7 is applied to a suitable audio-frequency amplifier and loud speaker.

The audio-frequency output of the circuit shown in Fig. 2 is a function of:—

(1) The oscillator voltage applied to the discriminator.

(2) The frequency variations in this voltage which are produced by the pick-up.

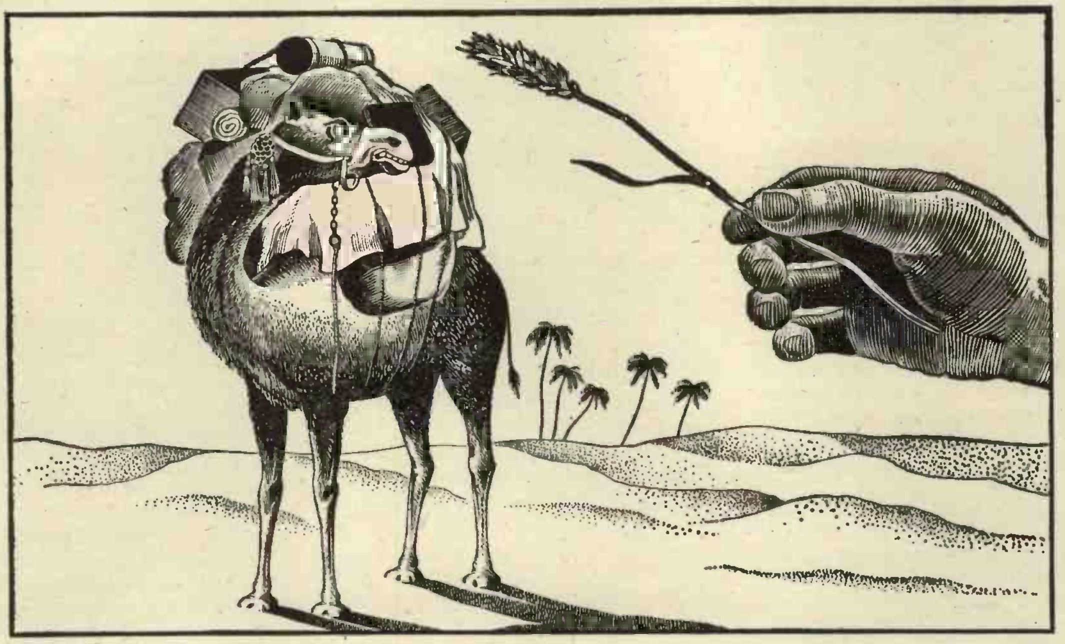
(3) The slope of the discriminator network.

(4) The audio voltage gain obtained from the 6R7.

An experimental pick-up employed in the circuit shown in Fig. 2 has given an rms potential of 6 to 8 volts across resistor R_8 when reproducing a 400-cycle record cut at a groove amplitude of 0.001 inch.

Response Characteristics of Pick Up and Tone Arm :

Making use of the equivalent diagrams in Figs. 3 and 4 the overall response characteristic of the system can be calculated. From these figures it can be seen that current i_3 represents the velocity of the ribbon with



Last Straw

AS the pace of production quickens, the care-laden manufacturer must often feel like a camel contemplating the approach of the last straw. Can his oft-revised schedule carry yet another complication? Can he increase output still further without some impairment of quality?

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respect to the insulated plate and current i_1 represents the velocity of the stylus. The ratio of i_3 to i_1 will provide the response characteristic of the pick-up with respect to frequency. For high-frequencies this can be calculated from the following formula

$$\frac{i_3}{i_1}=\left(\frac{C_3}{C_2+C_3}\right)\times\left(\frac{1}{1-(2\pi f)^2\frac{L_2C_2C_3}{C_2+C_3}}\right)$$

For low frequencies, the response characteristic may be obtained from

$$\frac{i_3}{i_1}=\left(\frac{C_3}{C_2+C_3}\right)\times\left(\frac{1}{1-(2\pi f)^2L_3(C_2+C_3)}\right)$$

It will be noted that two peaks in response occur, one at tone-arm resonance and one at the high-frequency resonance of the pick-up moving system. Fig. 5 shows the response characteristic as calculated from the above equations.

Tracking Weight Required to Overcome Vertical Force due to Lateral Velocity :

For proper tracking the stylus must have sufficient vertical force exerted upon it to overcome the vertical component of force due to the lateral velocity of the modulated record groove. Calculations have been made which show the vertical forces exerted upon styli of various radii when seated in a standard groove having an 88-degree included angle, a 0.0023-incn radius cutting stylus and a groove width at the top of 0.0069 inch. In addition to the vertical forces, consideration has also been given to the variations to be expected in pinch-effect with different sizes of reproducing styli.

Fig. 6 illustrates a stylus seated in a record groove of the above dimensions. Two important factors which change the diameter of the stylus are : the tracking diameter (d) and the wedging-angle (α). Tracking diameter d has a direct bearing upon both pinch-effect and the high-frequency response and should be kept as small as possible. On the other hand, the wedging-angle α, which determines the tendency of the stylus to climb the groove wall should be made as large as possible for specified grooves. From this it is obvious that a a compromise must be made. Fig. 7 shows the variations in d and α with stylus radius, and from observation it can be seen that the stylus radius should not be less than 0.0025 inch or greater than 0.0042 inch. Furthermore, since the curve for angle α is flat from a stylus radius of 0.0025 inch to 0.0042 inch and the curve for diameter d is rising rapidly over this range it appears desirable, when record groove variations are considered, to use a stylus radius of about 0.003 inch

As the stylus radius is increased, it is apparent that for a given groove velocity the output to be obtained at high frequencies will decrease. Calculations have been made of the expected loss at high frequencies, and Fig. 8 shows the curve for this tracking loss at 7,000 cycles for styli from 0.0015 inch radius to 0.005 inch radius. It will again be noted that a stylus radius of 0.003 inch is indicated.

Overall Response Characteristics

Fig. 9, curve A shows the overall response characteristic of the pick-up, tone arm, and discriminator as obtained from a frequency record having a 500-cycle crossover point between constant amplitude and constant velocity. The rounded portion of this curve at the crossover frequency is due to the limitations imposed by the electrical network used to provide the recording characteristic. For the purpose of comparison the calculated response characteristic previously shown in Fig. 5 is included in this figure as curve B. The departure from linearity of this curve represents a distortion of approximately 2 per cent. second harmonic and 0.1 per cent. third harmonic. The change in frequency which corresponds to the $\pm$ 0.0015-inch displacement of the stylus is $\pm$ 15,000 cycles.

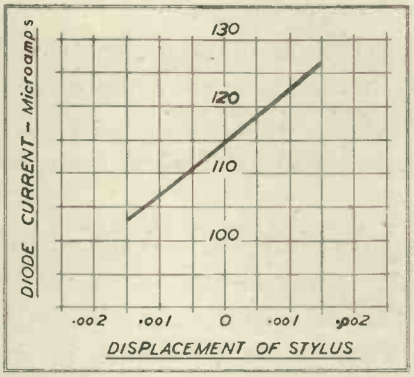

Fig. 10. Diode current and stylus displacement.

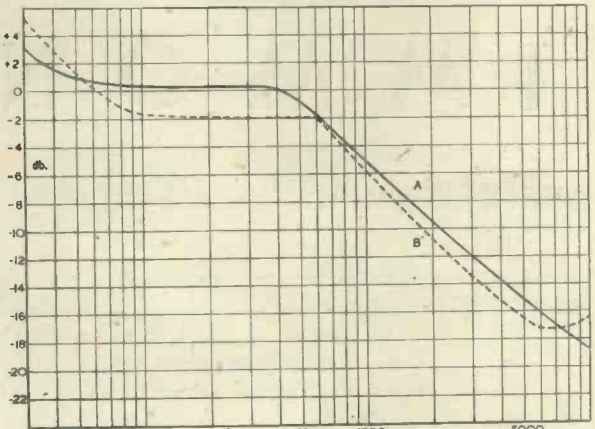

Fig. 9. Overall Frequency response of F.M. pick-up and discriminator.

Change in Diode-Current with Stylus Displacement

Fig. 10 shows the overall linearity existing between current in the diode resistor and displacement of the stylus. This curve shows the combined effect on linearity of the following factors :

(1) Change in the capacity of the pick-up with displacement of the stylus.
(2) Change in frequency of the oscillator with change in capacity of the pick-up.
(3) Change in output of the frequency discriminator-rectifier combination with change in frequency.

Conclusion

An experimental frequency-modulation record-reproducing system, of the type described, has been in use for some time. All the evidence to date indicates that the system is a practical one and is not adversely affected by changes in temperature, humidity, or line voltage.

The experimental frequency modulation pick-up meets the requirements of a satisfactory pick-up to a degree which has not previously been attained in a relatively inexpensive device. The general performance characteristics of a pick-up of this type can be calculated within reasonable limits.

From the listener's standpoint, the experimental frequency modulation phonograph system which has been described makes it possible when using conventional shellac records to extend the frequency range of a record-reproducing system to 10,000 or 12,000 cycles with surprising freedom from surface noise, mechanical noise, and distortion. Further reduction in surface noise can now be obtained with shellac records if they are recorded with a high-frequency accentuation characteristic which is comparable to that used in transcriptions.

The writers wish to acknowledge the valuable assistance of Messrs. H. Belar and R. Snepvangers during the development of the frequency - modulation record - reproducing system.

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BOOK REVIEWS

The Cathode Ray Oscillograph in Industry

W. Wilson, D.Sc. 144 pp. 156 figs. (Chapman & Hall, 12/6 net).

In his preface emphasising the ever-widening field of industrial application of the cathode-ray oscillograph, the author outlines his intention of meeting the need for guidance of those who could profitably employ the oscillograph, but who are not normally workers in this field.

The book deals with both types of tube, metal and sealed-off glass, and after describing their construction and the various accessories, discusses the various measurements which can be undertaken with the tube, including a number of less usual ones.

Two novel additions to the contents are a chapter on the Electron Microscope, and one on the care and maintenance of the tube and its accessories. This is particularly useful for those who use the tube as an instrument and have no previous experience of oscillograph practice.

Unfortunately, after reading this work, one cannot feel that the undeniable need for a book dealing with the oscillograph from the user's point of view has been really met. To succeed in this aim, a book must be explicit in the extreme, and as those for whom it caters are not likely to be able to correct errors and inconsistencies in the text for themselves, these are to be particularly avoided.

One is only too well aware of the difficulties of the author of a technical book under war-time conditions, but it is disconcerting to find errors in such abundance. For example, on p. 9 there is the peculiar physical concept that it is the vacuum and not the atmospheric pressure that holds a joint together, whilst in the same paragraph the term "high voltage" is used in mistake for "high vacuum."

Origin distortion is discussed on p. 11 and p. 36, but the two references do not appear consistent, nor do they fully explain the effect. The treatment of aberrations generally seems unsatisfactory as, apart from conspicuous omissions (such as the use of symmetrical deflection not only to avoid trapezium distortion, but also to minimise defocusing), the explanation on p. 38 for trapezium distortion takes into account only the second order effect of electron velocity and neglects the more important refractive aspect.

The reference to this effect in the description of the Cossor double-beam oscillograph is consequently at variance with the facts, whilst a little later in the description of this instrument the deflection coils are accused of being in between the inner and outer mu-metal shields, a statement which is neither true nor technically acceptable.

In addition to these there are unfortunately a great many more obvious errors, such as a reference to the ultimate vacuum of a rotary oil pump as 0.5 mm. Hg., and a statement on p. 20 that the vapour pressures of oil and mercury are 10^6 and 10^3 mm. respectively. Lissajous' name is also mis-spelt throughout.

In conclusion, one feels that in order to serve the purpose of this book best the author would have been better advised to include more detailed and accurate expressions of the fundamentals of the cathode-ray oscillograph and to rely on a complete bibliography to introduce workers in individual fields to the best way of applying the technique to their particular problems.

T.D.H.

Experimental Electronics

R. H. Müller, R. L. Garman and M. E. Droz. 322 pp. (Prentice Hall, Inc. N.Y. 29/6 English Price).

A remarkable thing about this book is that it is written by three professors of Chemistry. Not that they may not be fully qualified to write on such a subject, but there is the same feeling of surprise as if Professor G. W. O. Howe had written a book on Experimental Chemistry.

The authors acknowledge their indebtedness to standard works on electronics and radio engineering, such as those of Terman and Reich, and there are references to technical literature throughout, including a few British journals.

The introduction to the experimental work covers the usual elementary theory, and the experiments are then set out neatly with a preliminary note giving the purpose of the experiment, materials required, and procedure. A list of supplementary reading and problems is given at the end of each section. The series is complete and includes nearly all the work on valves which would be done by a third-year telecommunications student. Some of the experiments need days to make up, such as the three-stage inverse feedback valve voltmeter, or a beat-frequency oscillator, in which the student is apparently expected to start from scratch. This, of course, is all to the good, provided that the time is available in the course, and one wonders how the students and research workers in chemistry, biology and engineering at New York University find time to do it all.

As a guide for instructors or "home-study" workers it is one of the best books of its kind, and if all the experiments were diligently performed there would not be many practical applications of vacuum tubes that the reader would hesitate to tackle.

G.P.

Books reviewed on this page or advertised in this Journal, can be obtained from

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If not in stock, they will be obtained from the Publishers when available

X-Rays in Research and Industry

H. Hirst. 91 pp. 82 figs. (Tait Publishing Co. Pty., Melbourne, 7/6 English price).

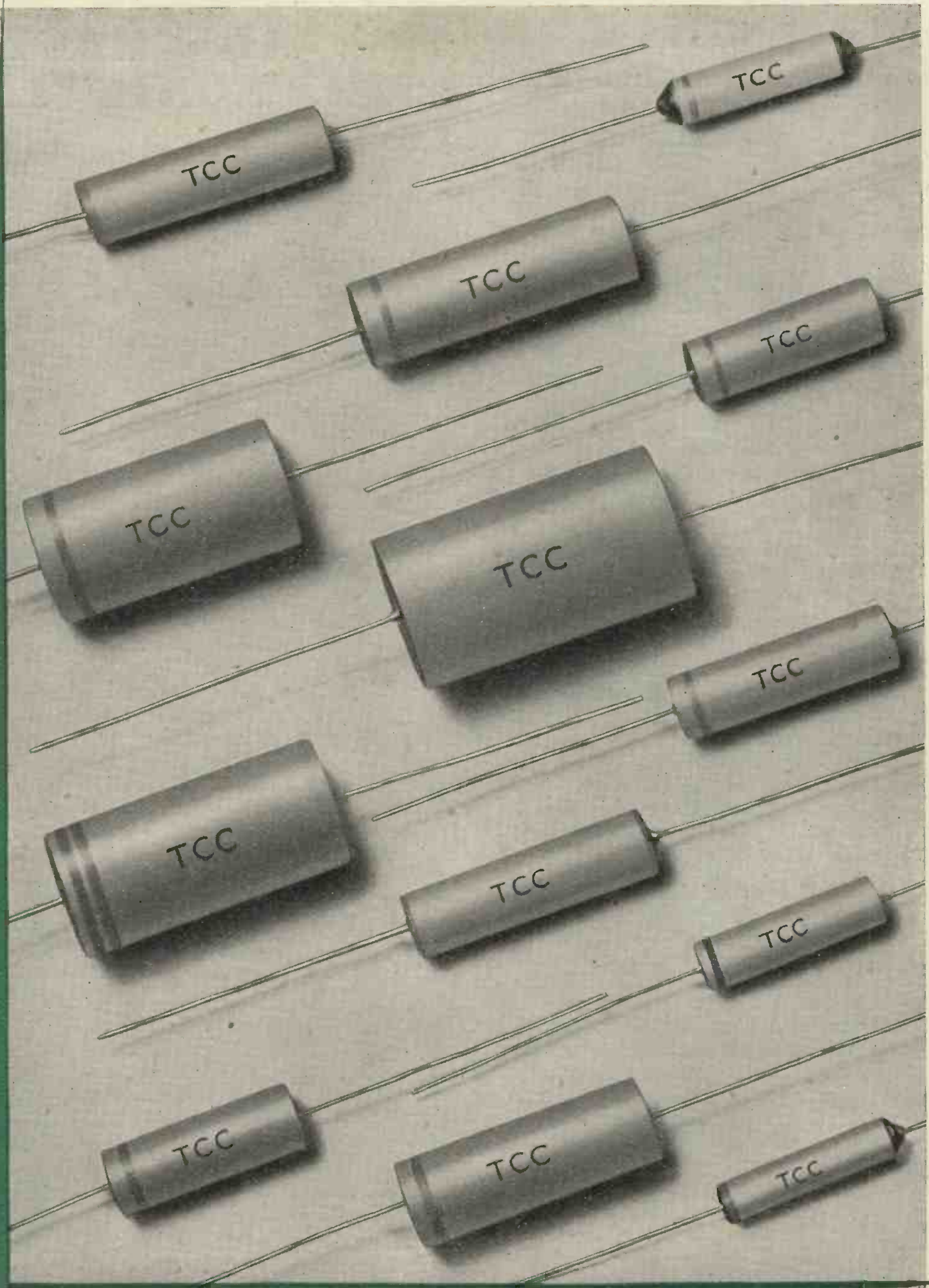
A handy book which describes the problems for which X-ray methods are of use, and the practice and calculations of X-ray technique.

After a description of the production and properties of X-radiation, there are chapters on crystal structure and crystallographic examination, investigation of alloys, castings, etc. The text is interspersed with numerous tables of data and the book is well illustrated. There is also a short bibliography. The whole work is a good summary of the application of X-rays to industry and is useful to have for reference.

Electrical Technology for Tele-Communications

W. H. Date (Longmans, Green & Co. 5s.)

In the review of this book which appeared in last months' issue, we regret that the title was given in error as "Electrical Technology for Radio Communications." The correct title is as given at the head of this paragraph.



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NOTES FROM THE INDUSTRY

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New Headquarters

The Council of the Incorporated Radio Society of Great Britain, announces that new headquarters have been established at New Ruskin House, Little Russell Street, London, W.C.1 (Holborn 7373), at which address the General Secretary (Mr. John Clarricoats) will be pleased to meet visiting amateurs.

Since September, 1939, the membership of the Society has increased from 3,500 to 5,500. Nearly 4,000 members are on active service.

R. W. Paul's gift to Research

In his will the late R. W. Paul has set aside a sum of over £100,000 for the endowment of a fund to pay for the design, construction and maintenance of novel physical instruments and apparatus required by research workers.

The trustees are particularly instructed to favour the construction of apparatus which gives no prospect of financial return.

The Committee entrusted with the administration of the fund will consist of six members appointed by the Royal Society, The Physical Society, The Institution of Electrical Engineers, and The Institute of Physics.

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DEAR SIR,—We have read the article, entitled "Safety with X-Rays —The Detection and Measurement of Radiation," by A. G. Long, which was published on pages 52-54 of the July issue of ELECTRONIC ENGINEERING, and we were interested to note the references to Cellophane, which appear in the particulars relative to Figures 4, 6 and 7 of the article.

It seems to us, however, that in those references the word Cellophane has been used in such a manner as might tend to create the impression that Cellophane is the name of a material.

One of the objects of this letter is to point out that Cellophane is not the name of a material, but that the word "Cellophane" is our registered trade mark, and denotes, exclusively and distinctively, the brand of cellulose sheets and films manufactured and supplied by us.

It is, of course, damaging to a trade mark that it should be used as the name of a material, and we feel sure, therefore, that you will not disapprove our writing to you to explain the position.—Yours faithfully,

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ABSTRACTS OF ELECTRONIC LITERATURE

RADIO

The Determination of the Location and Frequency of Thunderstorms by a Radio method
(*J. S. Forrest*)

A method is described of continuously recording atmospherics in order to obtain warning of the outbreak of a thunderstorm and to determine the distance of the storm from the recording site.

The apparatus consists essentially of a radio receiver tuned to approximately 150 kc/s and connected to a continuous chart output recording meter: a modulated oscillator is incorporated in order to maintain constant the characteristics of the receiver. The paper gives the results of three years' experience with this recording technique.

By correlating the output recorder deflections with the known locations of electric power system breakdowns due to lightning, the relation between the recorder output and the storm distance has been determined. For distances up to 600 km. the equivalent field strength of atmospherics at 150 kc/s, has been found to be inversely proportional to the square root of the distance of the source.

—*Jour. Roy. Met. Sec.* Jan., 1943, page 33.

Voltage Regulated Power Supplies
(*A. B. Bereskin*)

This paper discusses problems involved and develops an orderly procedure for designing and constructing these voltage regulated power supplies for specific applications. The correlation between design data and tests on finished model is shown.

—*Proc. I.R.E.*, Vol. 31 (1943), p. 47.

Loop Antennas for Aircraft
(*G. F. Levy*)

Characteristics, requirements and design considerations which are associated uniquely with aircraft loop antennas operating in radio range or beacon band extending from 200-400 kilocycles are discussed.

The "low-impedance" and the "high-impedance" types of air-core aircraft loops are considered in detail. Both types are analysed mathematically on the basis of their receiving efficiency and directive properties.

Actual polar characteristic curves are given for a number of loop antennas of both types. Iron-core loop antennas are considered separately and comparison is made with the more widely used air-cored types.

—*Proc. I.R.E.*, Vol 31 (1943), p. 56.

INDUSTRY

The Production of Fixed Carbon Resistors
(*F. C. Carter*)

The method of production of the various types of carbon resistor in common use in radio and line communication equipment is described. A feature is the employment of automatic machines producing large quantities of resistors of standard values.

—*P.O.E.E.J.*, 36 (1943), Pt. 1, p. 6.

Metallising Plastics
(*E. E. Halls*)

Some of the wide applications of metallised plastics are described; it is emphasised that metal coatings now have specific uses and are not used for decoration alone. A summary of the methods of applying the films is given and certain types of films discussed in detail, viz., films applied by means of metal powder in varnish or lacquer medium and cellulose lacquer films. Types of powders are discussed together with the best form and media in which they may be applied. Moisture proofing with aluminium is considered in conjunction with the electrical properties of organic bonded aluminium powder finishes.

—*Plastics*, June, 1943, p. 235.*

Heating Wood with R.-F. Power
(*J. P. Taylor*)

Radio-frequency power (of the order of 1-10 Mc/s) may be used to provide heat for various wood processes, such as seasoning, drying, etc. The method may also be adapted for plastic plywood and impregnated materials. A brief account of the theory of radio-frequency heating is given and the factors which determine its applicability discussed. Data for the calculation of power required, time cycle and operating costs are given.

—*Trans. A.S.M.E.*, Ap., 1943, p. 201.*

Resistance Welding Speeded and Improved Tube control
(*G. W. Garman*)

Two of the most important factors in welding are duration of current flow and the magnitude of the current. Details are given of the application of electronic control to the regulation of these quantities and the beneficial effects that have been obtained. A brief sketch of the development of a.c. electronic control is given from the first adoption of hot-cathode thyratrons to the modern water-cooled systems. Voltage adjustment and flexibility of the apparatus are described and energy storage welding discussed.

—*Electronics*, March, 1943, p. 117.*

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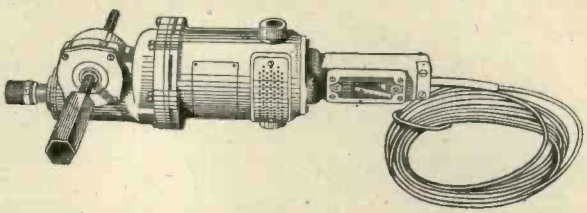

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A Note on the Puncture Strength of Porcelain, etc.

By Dr. Ing E. ROSENTHAL

In connexion with a recent article by the author: "Dielectric Strength of Porcelain and other Ceramic Materials,"* Mr. C. W. Marshall, of the Central Electricity Board, has pointed out that the value of the graphs would be increased if indications of the spread of the individual observations were made.

The following notes are therefore appended for reference:

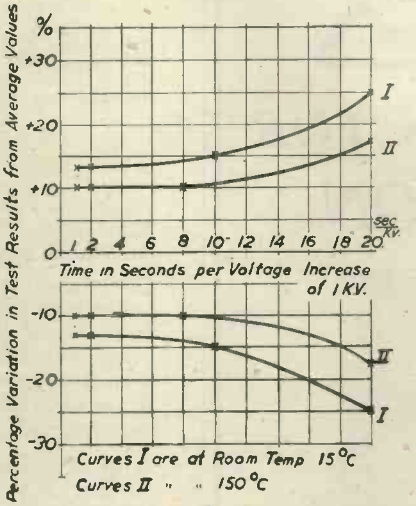
In order to obtain a reliable average value of the puncture strengths of a material, it is necessary to make a considerable number of tests. The American S.T.M. Standards only specify for porcelain a number of five, but a greater number gives a more reliable average.

The spread varies (a) with the frequency, (b) with the temperature, (c) with the duration and rate of increase of the voltage applied, (d) with the wave shape, and (e) with the electrostatic field distribution.

The spread is smaller at high frequencies and larger at low frequencies, and it is smaller at elevated temperatures compared with room temperatures.

In carrying out impulse tests, one observes a greater spread of punctures than at commercial frequencies.

* *Electronic Engineering*, March 1943.



The punctures lie closer together when the test arrangement excludes edge effects as far as possible. Edge effects tend to increase the spread of the observations.

It would, therefore, appear that there is a smaller spread in values in the case of thermal breakdown than is the case when the breakdown is preponderantly disruptive.

At normal power frequency (50 cycles per second), the spread can be as much as 25 per cent. up or down, although if the rate of voltage increase prescribed by B.S.S. 137, namely, 10 KV per second, is adhered to, the variation will only be of the order of $\pm$ $12\frac{1}{2}$ per cent. In other words, the more slowly the voltage is increased, the greater the spread of observations.

The graph given herewith was prepared by repeating twenty times tests at various rates of voltage increase. The horizontal ordinate indicates the number of seconds used for increasing the voltage by 1 KV. The twenty readings so obtained were added together and divided by twenty in order to obtain the average value. The highest figure above this average was then recorded above the horizontal ordinate, and the lowest figure below the average was recorded below the horizontal ordinate.

Curve (1) is for porcelain at room temperature (15° C.), and curve (2) is for porcelain at a temperature of 150° C. Although at first glance the spread of puncture values in the case of porcelain seems to be rather considerable, it is smaller than in the case of most insulating materials.

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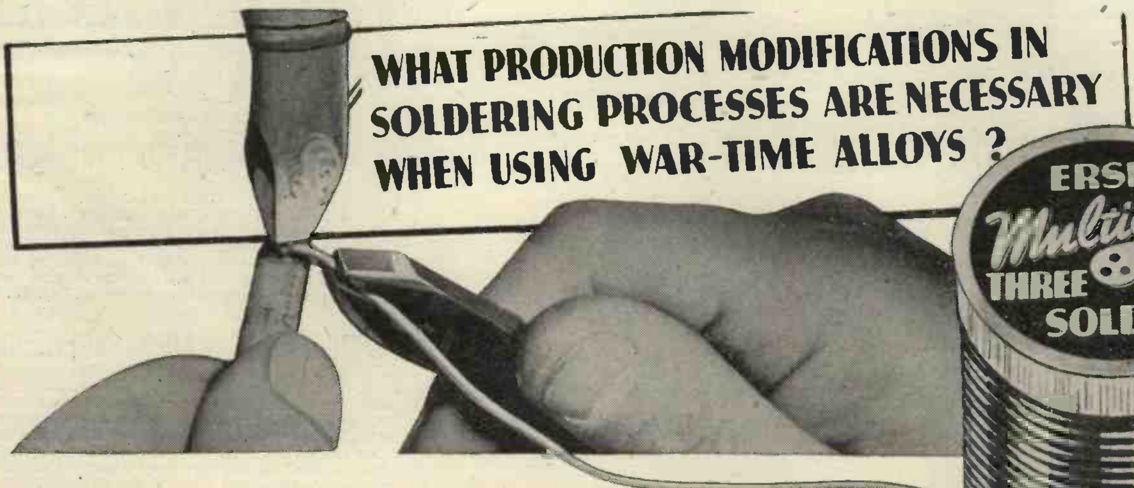

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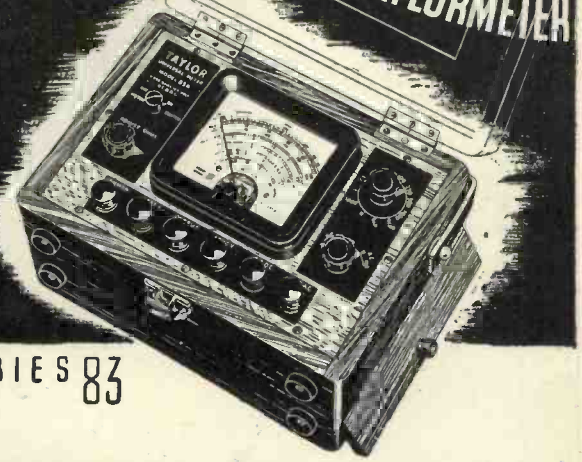

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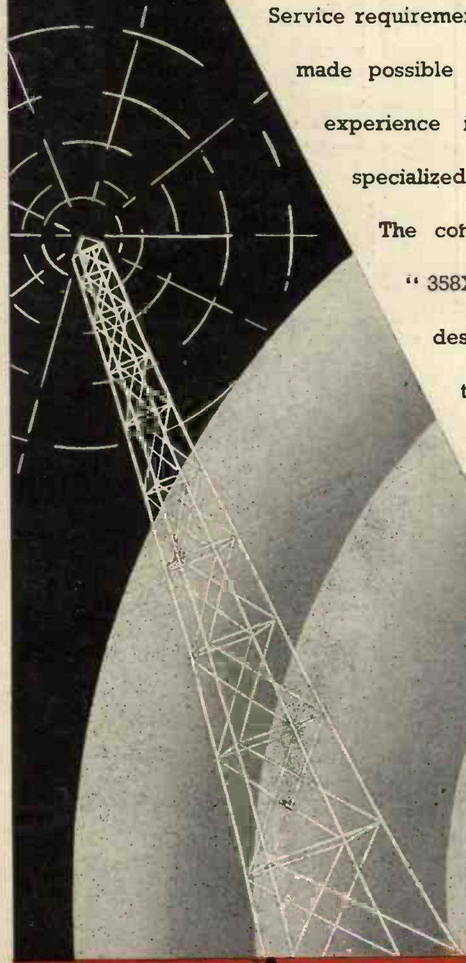

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